Anton Ulbeck

BULLETIN

OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. 3

W J McGEE, *Editor*

ROCHESTER
Published by the Society
1892

COUNCIL FOR 1892

G. K. Gilbert, *President*

Sir J. William Dawson,
T. C. Chamberlin, } *Vice-Presidents*

H. L. Fairchild, *Secretary*

I. C. White, *Treasurer*

Class of 1894

H. S. Williams,

N. H. Winchell,

Class of 1893

George M. Dawson,

John C. Branner,

Class of 1892

E. W, Claypole,

Charles H. Hitchcock, } *Members-at-large*

PRINTERS

Judd & Detweiler, Washington, D. C.

ENGRAVERS

Moss Engraving Co., 535 Pearl Street, New York

CONTENTS.

ILLUSTRATIONS.

(17 *plates*, 72 *figures*.)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA.

Regular Publications.

The Society issues a single serial publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, lists of Fellows, etc., and the latter embracing the larger papers accepted for publication. The matter is issued, soon as possible after acceptance, in covered brochures, which are at once distributed to Fellows and exchanges. The brochures are arranged for binding in annual volumes, which are elaborately indexed.

The Bulletin is sold to Fellows and the public either in full volumes or in separate brochures. The volume prices are, to Fellows a variable amount depending on the cost of publication; and to libraries and the public the fixed amounts given below. The brochure prices for volumes 1 and 2 are given on pages ix–xi of volume 2; the prices for the brochures of volume 3 are given below.

Volume 1, covering the work of the Society from the organization in 1888 to the end of 1889, comprises 593 + xii pages, 13 plates and 51 cuts. Price to Fellows, $4.50; to libraries, $5.00; to the public, $10.00.

Volume 2, covering the work of the Society for 1890, comprises 662 + xiv pages, 23 plates and 63 cuts. Price to Fellows, $4.50; to libraries, $5.00; to the public, $10.00.

Volume 3, covering the work of the Society for 1891, is now complete, and comprises 541 + xii pages, 17 plates and 72 figures. Price to Fellows, $4.00; to libraries, $5.00; to the public, $10.00. The volume is made up of 15 brochures as follows:

Brochure.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Proceedings of the Summer Meeting held at Washington. H. L. Fairchild, *Secretary*	1–152	0–2	1–32	$1.90	$3.75
Preliminary Notes on the Discovery of a vertebrate Fauna in Silurian (Ordovician) Strata. C. D. Walcott	153–172	3–5	1	.30	.60
Certain extra-morainic Drift Phenomena of New Jersey; On the northward and eastward Extension of the pre-Pleistocene Gravels of the Mississippi Basin. R. D. Salisbury	173–186	......	......	.15	.25
The Mannington Oil Field and the History of its Development; Fossil Plants from the Permian Beds of Texas. I. C. White	187–218	6	......	.40	.75
Notes on the Geology of the Valley of the middle Rio Grande. E. T. Dumble	219–230	......	......	.10	.20
Eleolite-Syenite of Litchfield, Maine, and Hawes' Hornblende-Syenite from Red Hill, New Hampshire. W. S. Bayley	231–252	7	1–3	.30	.55

Brochure.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
A Revision and Monograph of the Genus *Chonophyllum*. W. H. Sherzer	253–282	8	......	.35	.70
The principal Mississippian Section. C. R. Keyes	283–300	9	......	.20	.40
Two Montana Coal Fields. W. H. Weed	301–330	......	1–13	.35	.70
Paleozoic Formations of southeastern Minnesota. C. W. Hall and F. W. Sardeson	331–368	10–12	1–7	.50	1.00
Geology of the Taylorville Region of California. J. S. Diller	369–394	......	1–9	.30	.55
Jura and Trias at Taylorville, California. Alpheus Hyatt	395–412	......	......	.15	.30
Stratigraphy and Succession of the Rocks of the Sierra Nevada of California. J. E. Mills	413–444	13	......	.30	.60
The Geology of the Crazy Mountains, Montana. J. E. Wolff	445–452	......	......	.10	.15
Proceedings of the Fourth Annual Meeting, held at Columbus. H. L. Fairchild, *Secretary*	453–541, i–xii	14–16	1–7	1.15	2.25

Irregular Publications.

In the interests of exact bibliography, the Society takes cognizance of all publications issued either wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the Proceedings also are authorized to order any number of separate copies at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 3 have been issued:

Editions uniform with the Brochures of the Bulletin.

Pages	153–172, plates	3, 5—130	copies.	March	15,	1892.
"	173–186,	130	"	"	31,	"
"	187–218, plate	6—330	"	April	15,	"
"	219–230,	130	"	"	22,	"
"	231–252, plate	7—230	"	June	4,	"
"	253–282, "	8— 30	"	May	24,	"
"	283–300, "	9— 30	"	June	3,	"
"	301–330,	30	"	"	26,	"
"	331–368, plates 10,	12—130	"	"	23,	"
"	369–394,	230	"	July	15,	"
"	395–412,	280	"	"	15,	"
"	413–444, plate	13—100	"	August	8,	"
"	445–452,	30	"	"	8,	"

*Special Editions.**

Pages	3–13†, frontispiece	—100 copies.	March	25, 1892.		With covers.‡	
"	14– 15,	30	"	November	30, 1891.	Without covers.	
Page	15,	30	"	"	30, "	"	"
Pages	16– 22,	100	"	March	19, 1892.	"	"
"	23– 31,	100	"	January	22, "	"	"
"	32– 44,	50	"	"	22, "	"	"
"	44– 50, plate	1—100	"	March	24, "	With	"
"	50– 55,	100	"	"	19, "	Without	"
"	56– 59,	100	"	"	25, "	With	" §
"	59– 60,	30	"	"	19, "	Without	"
"	61– 64,	30	"	"	19, "	"	"
"	65– 68, plate	2—100	"	"	24, "	With	"
"	68– 79,	30	"	"	19, "	Without	"
Page	80,	30	"	"	19, "	"	"
Pages	80– 81,	30	"	"	19, "	"	"
"	81– 83,	200	"	"	19, "	With	"
"	83– 84,	30	"	"	19, "	Without	"
"	85–100,	300	"	February	26, "	With	"
"	101–109,	100	"	March	19, "	Without	"
"	109–121,	200	"	"	19, "	With	"
"	121–123,	30	"	"	19, "	Without	"
"	124–127,	200	"	"	19, "	"	"
"	128–132,	30	"	"	19, "	"	"
"	134–148,	30	"	"	19, "	"	"
"	148–149,	30	"	"	19, "	"	"
"	150–151,	30	"	"	19, "	"	"
"	455–458,	100	"	November	18, "	With	"
"	460–464, plate	14—150	"	"	18, "	"	"
Page	464,	30	"	"	15, "	Without	"
Pages	470–483,	30	"	"	15, "	"	"
"	483–484,	30	"	"	15, "	"	"
"	484–487,	30	"	"	15, "	"	"
"	488–495,	200	"	"	15, "	"	"
"	495–496,	30	"	"	15, "	"	"
"	496–500,	150	"	"	15, "	"	"
"	501–504,	30	"	"	15, "	"	"
"	505–508,	30	"	"	15, "	"	"
"	508–511,	30	"	"	15, "	"	"
"	512–514, plate	15—200	"	"	15, "	"	"
"	514–519, "	16—100	"	"	15, "	"	"
"	519–521,	100	"	"	15, "	"	"
"	523–530,	30	"	"	15, "	"	"
"	viii–ix,	30	"	"	15, "	"	"

* Bearing the imprint ["From Bull. Geol. Soc. Am., Vol. 3, 1891"].

† Fractional pages sometimes included.

‡ Pages 56–59 inclosed in same cover.

§ With pages 3–13 and frontispiece.

Reprints.

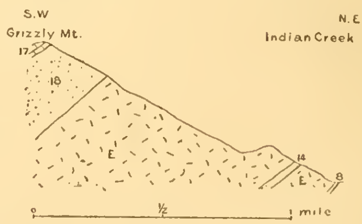
The matter published by the Society is occasionally reprinted, sometimes in part only, sometimes in extended or otherwise modified form, and incidental cognizance is taken of such reprints. The following reprint has been noted:

Volume 3, pages 283–300, plate 9: Reprinted with some additional matter under the title—The | Classification | of the | Lower Carboniferous | Rocks | of the | Mississippi Valley || A Dissertation | presented to the Board of University Studies of the Johns | Hopkins University for the Degree of Doctor | of Phiosophy || By | Charles Rollin Keyes. | 1892. | ——— | Washington: | Judd & Detweiler, Printers | 1892.

ERRATA.

Page 10,	line 15	from bottom;	*for*	"reënfore"	*read* reënforce.
101,	" 13	" "	"	"aquatic"	" agnostic.
103,	" 6	" "	"	"*Karstein*"	" *Karsteni.*
105,	" 12	" top	"	"twinned"	" tumid.
105,	" 14	" "	"	"ths"	" the.
106,	" 1	" "	"	"Centra"	" Central.
106,	" 3	" bottom	"	"probabilitles"	" probabilities.
107,	" 27	" "	"	"*Asterostoma*, n. sp."	" *Archæopreuster abruptus*, Greg.
107,	" 18	" "	"	"*Asterostoma*"	" *Archæopreuster.*
154,	in cut;		"	"Freemont"	" Fremont.
233,	" "		"	"Sawyer"	" Sawyer's farm.
233,	" "		"	"Spaulding Sch."	" Spaulding's farm.
369,	line 4	from bottom;	"	"Northern"	" North.
373,	" 4	" top	"	"northern"	" North.
373,	" 11	" "	"	"tufaceous"	" tuffaceous.
373,	" 9	" bottom	"	"Trias"	" Lias.
375,	" 4	" top	"	"tufaceous"	" tuffaceous.
378,	" 14	" bottom;	*after*	"*Section*" *insert*	*on northern side.*
378,	" 6–4	" "	*for*	"tufaceous"	*read* tuffaceous.
380,	" 16	" "	*after*	"*Unconformity*" *insert*	*on southwestern Branch of Peters Ravine.*
381,	in cut;		*to left of*	"N. E." *insert*	GENESEE.
381,	line 15	from bottom;	*after*	"*Mountain*" "	*through Genesee.*
389,	" 1	" top;	*for*	"*Northern*"	*read North.*
389,	" 5	" "	"	"northern"	" North.

390; *for defective cut substitute*



391, line	7 from bottom;	*for*	"northern"	*read*	North.	
392, lines 23, 20, 17, 11	" "	"	"	"	"	
393, line	8 " top	"	"	"	"	

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 1-152, FRONTISPIECE, PLS. 1, 2

PROCEEDINGS OF THE SUMMER MEETING HELD AT WASHINGTON AUGUST 24 AND 25, 1891

H. L. FAIRCHILD, SECRETARY

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1892

Alexander Winchell

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 1-152, FRONTISPIECE, PLS. 1, 2 MARCH 9, 1892

PROCEEDINGS OF THE SUMMER MEETING, HELD AT WASHINGTON, AUGUST 24 AND 25, 1891.

H. L. FAIRCHILD, *Secretary*.

CONTENTS.

Session of Monday Morning, August 24.

The Society met in the law lecture-room of Columbian University at 9.45 o'clock a. m., Vice-President G. K. Gilbert in the chair.

In the absence of Dr. J. C. Welling, President of the University, who was expected to welcome the Society, Acting President Gilbert spoke a few words of greeting, and, in behalf of the Society, welcomed the invited foreign guests.

ELECTION OF FELLOWS.

The Secretary announced the result of the balloting for the election of Fellows as follows:

William P. Blake, New Haven, Connecticut. Mining engineer.

Clarence Raymond Claghorn, B. S., M. E., Birmingham, Alabama. Economic geologist and mining engineer; now working on the geology of coal.

David T. Day, A. B., Ph. D., Washington, D. C. Chief of division of mining statistics and technology, United States Geological Survey.

Maj. Clarence E. Dutton, Ordnance Department, U. S. A., San Antonio, Texas. Formerly of the United States Geological Survey.

John Eyerman, Easton, Pennsylvania. Instructor in La Fayette College; Associate editor of the Journal of Analytical Chemistry, and of the American Geologist; now engaged in paleontology.

Eugene Rudolphe Faribault, C. E., Ottawa, Canada. Field geologist on Geological Survey explorations in Nova Scotia.

William Herbert Hobbs, B. Sc., Ph. D., Madison, Wisconsin. Assistant professor of mineralogy, University of Wisconsin; Assistant geologist, United States Geological Survey. Engaged in the study of crystalline schists.

Walter Proctor Jenney, E. M., Ph. D., Washington, D. C. Mining engineer, and Geologist, United States Geological Survey; now engaged in general geology of zinc and lead deposits of the Mississippi valley.

James Putnam Kimball, Ph. D., Washington, D. C. Geologist, now engaged in private practice.

George Edgar Ladd, A. B., A. M., Jefferson City, Missouri. Assistant geologist, Missouri Geological Survey; now engaged in economic geology.

JAMES RIEMAN MACFARLANE, A. B., Pittsburg, Pennsylvania. Editor of the second edition of the American Geological Railway Guide.
WILLIAM H. NILES, Ph. B., M. A., Cambridge, Massachusetts. Teacher of geology.
TIMOTHY WILLIAM STANTON, B. S., Washington, D. C. Assistant paleontologist, United States Geological Survey.

The following memorial of the deceased President of the Society, Dr. Alexander Winchell, was read by Professor N. H. Winchell:

MEMORIAL SKETCH OF ALEXANDER WINCHELL.

Fellow Geologists:

It is because of the courteous persuasion of some of the scientific and personal friends of my brother that I have undertaken the sad privilege of saying a few words in his memory. It were, perhaps, on some accounts more fitting that alien tongues should discharge this duty; but on other accounts it were more appropriate that a personal friend should speak of him, from the intimacy of his acquaintance and from the love that springs from many years of community of interests and constant intercourse. To you who knew Alexander Winchell well, no words that I shall utter, however they may be tinged by a brother's partiality, will appear extravagant; and to you who did not know him well, I shall hope to convey some idea of his personality and his work.

This occasion will not permit an exhaustive analysis of his scientific work. I shall hope at another time to treat of that more fully. I will only call your attention to the prominent traits of his personal character, and to some of the epochs of his professional career.

Alexander Winchell was born in the town of Northeast, Dutchess county, New York, December 31st, 1824. He died at Ann Arbor, Michigan, February 19th, 1891.

His work was many-sided and voluminous. As a youth and young man, he excelled in mathematics and had a leaning toward civil engineering and astronomy as a field for his life's energies. This facility of mathematical reasoning has given cast to some of his later philosophical speculations, in which his arguments are connected and expressed in algebraic form. Later he spent two years at South Lee, Massachusetts, with a venerated uncle, a leading physician of Berkshire county, making preliminary preparations for the medical profession. About this time also his parents and some of his trusted advisers urged upon him the Christian ministry. These early inclinations had their effect on his later life, and appear prominently in his predilections for physiological and theologico-scientific writing. He delighted in music and poetry

and sculpture; and his keen esthetic taste, united with a ready apprehension of esthetic truth and a lively imagination, have produced a large mass of exquisite poetic composition, never published, or but partially published. He became, at Ann Arbor, a patron and an influential promoter of the musical interests of the city and of the university, having served for several years prior to his death as president of the University Musical Society. He had a quickness of perception of physical form, and a deftness in mechanical construction. These resulted in some modeling in plasterof Paris, as well as in many hand-sketches and drawings. To his college training in Latin and Greek, he added Hebrew, German and French; and later, along with Spanish, he also acquired a sufficient knowledge of the Scandinavian to enable him to read the scientific works in which he was concerned in these languages.

The fortunes of his birth not having afforded him the means and opportunity to devote himself at once and uninterruptedly to any chosen line of professional labor, he resorted to teaching as a double means of financial revenue and of personal improvement. In this he was rapidly promoted; but this rapid promotion was due more to his scholarship and his success as a leader of his best pupils than to any personal magnetism or sympathy which he inspired in his classes as a whole. He had no care for laggards, and only a passing regard for the indifferent or mediocre; but for the student who manifested a special earnestness, or exhibited more than a casual interest in natural science, he was ready to spend any amount of extra time and to render unselfishly any service that might be required. He passed rapidly through the lower grades of the teacher's profession to that of a full professor in the department of science which he had chosen. The teaching profession brought him frequently upon the lecture platform, and his earnest interest in the educational and social issues of the day, as brought out in the leading periodicals, prompted him to participate in the discussion of them. As his contributions on the issues of scientific instruction and scriptural interpretation always bore the impress of Christian faith and of scientific as well as philosophical acumen, he was marked as a defender of the Christian church against assaults which scientific men had made upon it. These qualifications, admired by the scientist no less than by the Christian educator, recommended him for still higher promotion, and he was elected and inaugurated as chancellor of Syracuse university, at Syracuse, New York.

He soon discovered, however, that the financial and other vexatious details of university administration absorbed all his energies, and as there was no likelihood of relief, he, contrary to his expectation when he accepted the position, promptly resigned and accepted again a pro-

fessorship in the same institution. It was during his residence at Syracuse that were laid the first lines of an episode in his professional career which was to become the most distinctive event of his life. He gave by invitation a series of papers in the *Northern Christian Advocate* on "Adamites and pre-Adamites," which were published in pamphlet form. This had been preceded by a lecture on the same subject before the Bible class of the Methodist church at Syracuse, and was followed by an article on "Pre-Adamites" in McClintock and Strong's encyclopedia. In this he singled out the Noachian descendants as of later origin than several other branches of the human family, and, without contravening any of the statements of divine scriptures, attempted to show wherein some of their current interpretations ought to be corrected. The whole effort was one of those far-reaching expositions of scriptural and scientific harmony for which he was becoming famous, and which only required for their universal acceptance the abandonment or modification of some dogmas of human origin. He had been lecturing on geology four years, at Vanderbilt university, at first dividing his time between that institution and Syracuse university; but these views were supposed by the authorities of Vanderbilt to be heretical, and when he refused to decline a re-appointment in May, 1878, the lectureship which he held there was unceremoniously abolished. This act, which flavored of the proscriptions of the middle ages, created a profound sensation in educational circles. He received such a spontaneous and instant sympathy and support that, smarting under the injustice of trial and conviction and punishment without the opportunity of defense, he elaborated the work of the pamphlet on "Adamites and pre-Adamites" into an attractive volume of five hundred pages, which was published in 1880. This volume may be taken as the type of a large number of publications, partly theological and scriptural and partly scientific, which won for him the respect and confidence not only of numerous scientific students but also of many churchmen, and which have served to allay the fears of many as to the attitude of scientific men generally toward Christianity.

On his return to the university of Michigan in 1879, he resumed more strictly scientific work; but the multiplied demands made upon him for scientific contributions of a more popular character interfered seriously with his plans. Within the first three years appeared not only his "Pre-Adamites," but "Sparks from a Geologist's Hammer" and "World Life." On the last he spent more time than on any of his former publications. It is an amplified reproduction of principles and discussions which he had presented in more or less fragmentary form in public lectures during several years, and fills the place in the realm

of physical science in its relation to the Christian faith which the "Pre-Adamites" fills in the realm of anthropology. In rapid succession followed "Geological Excursions;" "Geological Studies, or Elements of Geology" (1886); "Walks and Talks in the Geological Field" (1886), 'Shall we teach Geology?;" and three annual contributions to the reports of the Geological Survey of Minnesota, the last of which, "American Opinion on the Older Rocks," reached him in printed form but a few weeks prior to his death.

This is the merest skeleton-sketch of the busy life and fertile pen of Alexander Winchell. It takes no note of his daily labors in the class-room, nor of his minor papers, some of which are lengthy and involved the severest study, nor of his technical geological work as director of the geological survey of Michigan. This was all interspersed again with public addresses at commencements, and platform lectures in nearly all parts of the United States. No one can give attention to the multiplicity of the avenues of his labor without experiencing a profound conviction of his untiring industry and versatility, and at the same time of the breadth and depth of his intellectual capacities.

The full number of his literary compositions published, according to a list kept by himself, is five hundred and sixty-six. He described seven new genera and three hundred and four new species of organisms, mostly fossil, and sixteen new species were named for him by other paleontologists. There remain unpublished numerous poems, minor manuscripts and journals, and the larger part of a volume on "Intellect and Religion," as well as an uncompleted memoir for the United States Geological Survey on Carboniferous and Devonian fossils—an amplification of his work on the "Marshall group" based on his collections for the Michigan geological survey and on other collections made later.

It is evident to the most casual observer who considers the volume and variety of his literary work, that he was a man of strong personality and that he was dominated by the strongest convictions. The firmness and the depth of all his mental movements were equalled only by their enduring constancy and their untiring activity. He was from boyhood physically strong, and in his manhood he was rarely interrupted by bodily ailment. The stealthy disease (aortic stenosis) which finally surprised him and us was probably upon him for many years, but it did not prostrate him nor even incapacitate him for more than a few days. He was in the midst of a popular course of lectures before the geological society of the university of Michigan; three had been given on "Evolution," but the fourth and last, which was specially entitled "Philosophy of evolution,"

was temporarily postponed, owing to increasing debility and the direct advice of his physician. It was to have been given February 6. On the small-page hand memorandum containing the catch-words of the argument of each lecture, from which he elaborated his theme extemporaneously, and which was found on his desk after his funeral, he had, in pencil, inserted an arrow-point denoting the place at which the course was interrupted. This being absolutely his latest public work, it has a melancholy interest and value, and the entire page is here appended:

Evolution.

Its principles and proofs, popularly discussed in four lectures, under the auspices of the Geological Society of the University of Michigan.

Jan. 16.—*World Evolution.*

The method of world-origin, world-growth, and world-decay; the same for all worlds. The spectacle of the universe, unity of method, and unity of creative intelligence. Divine plans and basis of intercommunication among the populations of all worlds. Evolution the unifying conception.

Jan. 23.—*Organic Evolution.*

I. *The March of Extinct Life.*—The method of its march through the ages. The germinal conceptions evolved in time. The vertebrate type in its secular expansion. Advent of man. His organic evolution past its culmination. Man the subject of psychic evolution. Commencement of physical decadence.

Jan. 30.—*Organic Evolution.*

II. *Heredity and Variability.*—Conditions of variability. Environment and adaptation. Examples of variation.

III. *Morphological Evidences.*—Family resemblances. Blood resemblances. Visible kinships among animals. Common descent.

IV. *Embryological Data.*—Parallelism of embryonic histories. Parallelism with gradations of animals. Parallelism with paleontological succession. The three parallels illustrated by a diagram.

Feb. 6.—*Philosophy of Evolution.*

What is Darwinism? Misapprehension of causation. Relation to environment conditional; not casual. Cause acts now and here. The efficient cause in the organism. The efficient cause immaterial. The efficient cause discerning. Evolution reveals the universe as one empire; establishes the unity of creative intelligence; and proves human kinship with the infinite mind.

To these lectures such large numbers of auditors, both students and citizens, flocked that they were driven from the room which was his

lecture room, first into the law lecture room, and then into the general assembly hall of the university, where it was estimated that from twelve hundred to fifteen hundred listeners waited and were instructed for an hour and a quarter on the occasion of his third lecture. This was the last time he was outside of his home, and he was so weak that some friendly students literally bore him to the carriage which was waiting to convey him back.

He certainly expected to recover so as to be able to deliver the final lecture of the course, though evidently there were misgivings—misgivings whose shadowed presence in his calculations for some months previous can be read from small acts and sayings which are now recalled, but which at the time attracted but little attention.

After he had definitely chosen as the arena in which he should work out his professional career and had been appointed to teach the natural sciences, there are distinctly two epochs in his life which are separated from each other by an important official event. The first epoch is that which is marked by his devotion to rigorous scientific investigation, the *discovery of the unknown*. The second epoch is that marked by his broader grasp of things already known in science, and his *classification of the known into system*. It will not be correct to suppose that he wholly abandoned one when he took up the other, or that he did not already labor in the latter before he gave up the former; for throughout his life he was ready to engage, and did engage, in either as opportunity was presented. Still, he did himself make announcement of this transition from the special to the general in his scientific labor. This distinction and division were instituted by his giving up of the geological survey of Michigan and abandonment of all hope of future work in that direction, and were accentuated later by his acceptance of the chancellorship of the Syracuse university. The war of the Rebellion interrupted the Michigan survey in 1861, after two years of successful field and laboratory work. The official result of these two years is embraced in a volume of 339 pages, printed in 1861.* But the most valuable results appeared unofficially in later publications, chiefly in the proceedings of the Academy of Natural Science of Philadelphia, the American Journal of Science, and the proceedings of the American Philosophical Society. During the eight years that elapsed before the survey was revived (1869) he was mainly engaged, so far as strictly geological work was concerned, in elaborating its paleontological results and in special surveys of limited districts with special reference to their economic resources. Thus he became familiar with the geological conditions of the salt and petroleum rocks of Michi-

* First Biennial Report of Progress of the Geological Survey of Michigan: Lansing, 1861.

gan, Ohio and Canada, on which he made special studies. In respect to the salt-bearing strata of Michigan he established the basin-shaped form of the strata, and defined not only the principles but also the geographic area in which brine might be found. His chief geological problem, however, during this interim was the establishment and defense of the "Marshall group," which on paleontological, historical, and stratigraphic evidence comprises a great series of Subcarboniferous strata which, as a body, belong together, although they had in part been embraced severally under the names Catskill, Waverly, Kinderhook, Goniatite limestone, Yellow sandstone, Chouteau limestone, and Siliceous group.*

On the resumption of the survey in 1869, he was chosen director by the geological board and entered upon his duties with great zest. The eight years that had passed since it was interrupted had broadened his views and qualified him, by his more extended acquaintance with the state and with its geology as well as with the geology of adjoining states, to carry on the survey rapidly and effectively. Preparatory to the meeting of the state legislature he drew up a report of progress† and had put into print a plan for his final report. Unhappily, complications of personal and political nature arose and threatened the success of the survey, and my brother resigned his commission.‡ The geological board never appointed a successor but parcelled out the survey to different geologists; and their separate reports, conceived and prepared in accordance with the plans of the director, were subsequently published as official reports on the geology of the state.

Thus my brother was turned from his chosen field of special geological research and led into the broader domain of systematic study, undoubtedly to the loss of the citizens of Michigan but to the benefit of the wider circle of readers of his later writings.

We do not, however, enter within the domain of Alexander Winchell's greatest achievements until we consider his broader discussions of the relations of modern science to education, to culture, and to Christian faith, and his contributions to natural theology. He imbibed from his boyhood training a profound reverence for the holy scriptures, and his whole life was a testimony, no less in its daily manifestations than in its consecration to correct biblical interpretation, to his belief in their teachings. While he accepted and defended the integrity of the Christian faith, he insisted with equal pertinacity that Christian faith must have

*The Marshall Group: A memoir on its Geological Position, Characters and Equivalents in the United States. Proceedings Am. Phil. Soc., vols. xi and xii, 1869 and 1870.

†Report on the Progress of the State Geological Survey of Michigan. Presented to the Geological Board Nov., 1870; Lansing, 1871. 8vo, 64 pp.

‡The circumstances which led to the resignation are caricatured in "Sparks from a Geologist's Hammer" under the allegory "A remarkable Maori manuscript."

and does have a rational foundation and sanction in human reason; and he ascribed the conflicts between science and religion which have been insisted on both by Christian theologians and by atheists to wrong ideas of the relations that subsist between them and to dogmatic interpretations and traditions—or else to the weakness of the light which reason has been able to derive from the flickering flame of science, or from the glare of profane history. His position among the scientists of America in this respect was sometimes bold and often unique. His earliest scientific thinking and his first public addresses were cast in a mold of theistic faith. Although the mold was compelled to grow through various enlargements and modifications, it was never thrown aside. Thus, in 1857, he addressed a bible class at Ann Arbor on "Theologico-geology, or the teachings of scripture illustrated by the conformation of the earth's crust;" and in 1858 his final lecture of a course before the Young Men's Literary Association of Ann Arbor, was entitled "Creation, the work of one intelligence and not the product of physical forces." His hesitancy in the adoption of evolution as the method of organic development of species continued only so long as he was unable to give it sufficient examination to define its bearings on his conception of divine agency in creation. His small work, "The Doctrine of Evolution; its Data, its Principles, its Speculations, and its Theistic Bearings" (1874), was the result of that preliminary examination. He sat down to the task with an expectation to reach an adverse conclusion. He rose from it satisfied of its theistic basis—*the panurgic energy of evolution is the divine intelligent will*, the single synthetic force of which all other forces of matter are but specialized forms. This central conception once established, it was his delight, as evinced in hundreds of lectures and in all his later publications, to group the phenomena of physical and organic nature about it, and to reënfore it by all the eloquence and philosophy and learning which he could command. It was the central conception and the designed finale of that last course of lectures from which death snatched him away.*

In scientific education he bore a conspicuous and burdensome part. Going to the university of Michigan in 1854, he found a young state institution in a crude state of organization and without any definite recognition of the natural sciences as factors of culture and as necessary elements in a college curriculum. He went energetically to work to

*He was advised by many during the past two years to issue a revised edition of his "Doctrine of Evolution," but he steadily declined, for he had in mind the publication of a thorough treatise on evolution as a sequel to that work. He considered his "Doctrine of Evolution" as a sort of court trial of the cause of evolution by a judicial and impartial mind. That trial concluding with a verdict favorable to evolution, he wished to himself take the position of an advocate and to prepare its strongest affirmative argument.

influence public opinion. He was conspicuous in the State Teachers' Association, of which he was soon elected president. He wrote numerous reports and appeals and resolutions, and in 1858 he was charged with the editorship of the *Michigan Journal of Education*, which, with great tact and distinguished ability, he made to tell the story of the natural sciences and to plead for scientific instruction in all the schools. His objective point was to introduce natural science in a systematic manner into the secondary schools of the state, and through them to feed the state university with a class of students that would expect and demand a higher grade of scientific instruction from that institution. He never wearied in this effort, some of his latest publications (*e. g.*, "Shall we Teach Geology?", 1889) voicing the same plaint in louder and more immediate appeals. He urged the university authorities, who to him manifested a lethargic indifference, to consider the needs of the institution in this particular, to plan for greater facilities for teaching the sciences, and to build up greater attractions to the student scientifically inclined. He pointed, with a tinge of humiliation, to the newer institutions of like grade further westward which have outstripped the university of Michigan in scientific appliances, having caught the moving spirit of the times and having made provision for a future career in natural science which has yet to be entered upon at Ann Arbor. "That, also, goes for nothing," said he, not ten days before his death, as he sorrowfully pointed to some rejected plans for a new science hall at Ann Arbor, which had been devised jointly and had been presented unsuccessfully to the authorities of the university. I understood that the legislature, then in session, had not been asked to make provision for it in the stated appropriations. Future years, however, will reveal to the people of Michigan, and especially to the regents of the university, the great difficulties with which he had to contend, and they will hasten to repair the great defect which his sagacity pointed out and which his labor aimed to remedy.

Cognate with his efforts to build up directly a scheme of higher scientific instruction in the schools were his efforts to popularize science among the citizens at large. His work "Sketches of Creation" (1870) has had an enormous sale. It proves the eagerness of the enlightened American citizen to penetrate, albeit not through the avenues of technical science, into the recesses of profound scientific truth and imagination. One of the greatest services which he rendered to geology was to clothe its great truths in attractive words adapted to the masses. The thousands who have read "Sketches of Creation" or "Walks and Talks in the Geological Field," will, should occasion arrive, testify to the cultural as well as the economical value of geology. Such occasions arise annually in the state legislatures and in our educational boards, and no one can estimate the influence which his beautiful popular essays have had in

bringing about the present multiplicity of geological surveys and opening the avenues to favorable legislation by the states of the Union and by the United States congress.

Time will not permit me to enter upon a special study of his separate publications, however inviting and profitable it might promise. We can here only sketch some of the grander steps of his life, and bear our tribute to his goodness, his untiring industry, and his single-minded consecration to the truth. As geologists we have to acknowledge ourselves deeply indebted to him; for he explored in advance of us some of the deepest and darkest recesses of our science; he scanned the heavens of all science and all philosophy, and he brought forth new things and classified old facts which before had been chaotic or contradictory. His imagination served him as a scientific guide to unknown realms; his language clothed his descriptions with beauty and his ideas with definiteness and reasonableness. As a rhetorician few have excelled him; as a popular scientific expositor, and especially as the harmonizer of apparently conflicting truths in science and religion, none have equalled him. He constructed an arch and put in the keystone connecting two independent pillars of truth. He was able to stand and to work on either of these pillars; and, being so able, he saw that they were designed to sustain the same great superstructure. The pillars are revealed truth and natural truth, and the superstructure is the unison and harmony of all truth.

My duty would not all be done did I not refer to his relations to this Society, and his agency in effecting its successful organization. He was among the first to see the need of this organization, and coöperated with the preliminary committees. The Society, however, as an actuality, made but little headway until the Cleveland meeting, where he was made the presiding officer; and by his judicious selection of committees and the drafting of a preliminary constitution the Society was formally organized, and a large number of influential geologists then present signed the preliminary articles. Since then he has been uninterruptedly in the service of the Society. He has attended every meeting of the Council and every meeting of the Society, having presided, in whole or in part, at every meeting of the latter. Our constitution was drawn up by him in the first instance. It is not too much to say that if to any one belongs the title of "Father of the Geological Society of America," it is to Alexander Winchell. The Society, therefore, to-day for the first time draped in mourning, has lost not only its present chief officer but its strongest friend and promoter.

In conclusion: We cannot now fully realize the loss which the death of such a geologist inflicts on the science of geology in America. He was

not all the time active in the fighting camp of the fray, but he was always in the great contest. He was organizing the forces, and laying far-reaching plans for campaigns which the future alone will work out; he was rallying the reserves by public enlightenment on the issues and utility of all science. He increased our friends and disarmed our foes. He propitiated many who were hostile or indifferent. His influence was felt where it was little suspected. The next generation, scanning the history of the present, will detect the agency which he bore out in the scientific and particularly in the geologic movements of this, and the next century can best point out the men who, in the closing years of the nineteenth century, bore the great burdens and discharged the great functions on which the progress of truth and the increasing happiness of man depend.

Following the reading of the memorial, it was moved by Professor Charles R. Van Hise and unanimously voted that a special committee of three be appointed to prepare and submit to the Society resolutions in expression of the sentiments of the Society regarding the death of President Winchell. The chair appointed as such committee Edward Orton, Charles A. White, Charles R. Van Hise.*

No reports of committees were presented and no miscellaneous business was offered. After announcements regarding the sessions of the Society and of the approaching International Geological Congress, Acting President Gilbert declared the scientific work of the meeting in order, and announced the first paper upon the printed program:

A GEOLOGICAL MAP OF SOUTH AMERICA.

BY PROF. DR. GUSTAV STEINMANN, OF THE UNIVERSITY OF FREIBURG, GERMANY.

(*Abstract.*)

This geological map of South America forms a part of the geological section of the "Physikalischer Atlas von Berghaus" (Gotha: J. Perthes). There are many resemblances which have existed between the two Americas up from Paleozoic time. So the Devonian fauna of Bolivia connects the North American faunas of that age with those of Brazil, Falkland islands, and South Africa. In both regions, during the Triassic and Jurassic periods, marine deposits were not formed on the greater part of the continent, but at the commencement of the Cretaceous period large areas were covered by the sea, especially in the northern part of South America (Brazil, Colombia, Venezuela, etc.) and in the southern part of North America (Mexico, Texas, etc.). In southern Chile there exists a continuous series, partly of Cretaceous and partly of Tertiary age, which seems to be analogous to the Chico-Tejon group of California.

*The resolutions appear in the proceedings of August 25.

The glacial deposits seem to have a much greater extent in South America than has been supposed. In the cordillera of Capiajo moraines are found at a height of about 1,200 meters above sea level, and Raimondi, twenty years ago, described the same deposits from the department of Ancachs, in Peru (about 9° south latitude), reaching down to about 2,500 meters above sea level. These facts merit our attention with regard to the theory concerning the alteration of the terrestrial axis or the contemporaneity of the glacial periods on both hemispheres.

The paper was discussed by E. D. Cope, R. T. Hill, and C. A. White. Mr. Hill thought there would probably be found some correspondence between the Cretaceous of the western coast of South America and that of the United States. Dr. White spoke as follows:

My own investigations with relation to South American geology, to which Dr. Steinmann has referred, have been confined to the Cretaceous invertebrates of Brazil. When studying the fauna, which was collected by members of the survey under Professor Hartt and sent to me for that purpose, I was not able to identify a single species with any North American form. Neither was I able to detect any close affinity between the Brazilian fauna and that of any North American formation. On the contrary, I found that a considerable number of the Brazilian forms were closely like a part of the Cretaceous fauna of southern India, and some of the species I treated as being identical. I was not then, and am not now, able to say that all the species which were sent to me came from one and the same stage of the Cretaceous series. If they did, there is certainly a remarkable commingling of earlier and later Cretaceous types. I do not think such a commingling is improbable, and I therefore treated the collections sent to me as a faunal unit, and in summing up all its characteristics I referred it to the Neocomian.

In reply to questions Dr. Steinmann said that enormous beds of eruptive material were found between thin bands of limestone; that continuous eruptions of all kinds of volcanic rocks took place in the Chilean cordillera during Jurassic and Cretaceous time. In eastern Brazil there is conformity between the Carboniferous and the lower Cretaceous, which rests upon the former. The Paleozoic rocks are metamorphosed; the later are not.

The full paper is printed in the *American Naturalist*, vol. xxv, 1891, pp. 855–860.

The next paper was entitled—

ON THE PERMIAN, TRIASSIC, AND JURASSIC FORMATIONS IN THE EAST INDIAN ARCHIPELAGO (TIMOR AND ROTTI).

BY DR. AUGUST ROTHPLETZ, OF THE UNIVERSITY OF MUNICH, GERMANY.

In discussing this paper Dr. C. A. White remarked:

The paper which has just been read by Dr. Rothpletz is of peculiar interest to me because some late studies of mine in Texas are of a similar character. These discoveries in their essential character are similar to those of Waagen in India,

Karpinsky in Russia, and Gemmellaro in Sicily. They show that a large proportion of the faunal types which have long been regarded so characteristic of the Mesozoic began their existence before the close of Paleozoic time, and that these forms often constituted members of faunas which embraced well-known Carboniferous species. They also show, what we ought always to have expected to find, that upon the confines of systems and formations there was necessarily a faunal gradation from the earlier to the later divisions.

Professor Lester F. Ward spoke as follows:

I am glad to observe that the invertebrate and vertebrate paleontologists are beginning to discover that the evidence of the fauna relative to the age of the deposits of the southern hemisphere is not as harmonious as was originally supposed. With regard to the plants, we are not of course as yet in condition to make any very broad generalizations, but we have at least reached a point where we can propose a hypothesis which, however much it may require to be modified, is certain to lead in the direction of ultimate truth. This hypothesis is briefly this: At an early period in geologic history there flourished in both hemispheres a vegetation which is commonly understood as the Carboniferous flora, consisting of the lepidophytes, calamites, and marattiaceous tree-ferns, together with the genus *Cordaites*, alone representing the phanerogams. In the southern hemisphere, in addition to this Carboniferous flora and contemporaneous with it, there existed another and quite different type of vegetation which we now call the *Glossopteris* flora. When the great Permian glaciation of those regions came on, the true Carboniferous flora proved incapable of supporting the lowered temperatures and succumbed. The *Glossopteris* flora, on the contrary, consisting largely of the primordial representatives of higher types of vegetation—cycadaceæ, coniferæ, etc.—survived, persisted, and underwent great modification. In its modified form it came at length to constitute the now well-known Mesozoic flora of Australia and India, the types of which can be traced back into the Paleozoic. This Mesozoic flora of the southern hemisphere, already found in southern Africa and in South America, which also contain true *Glossopteris* types, not only persisted long in these regions but migrated northward and is now found, altered it is true but distinctly recognizable, throughout vast areas of the northern hemisphere. From India it found its way to Cochin-China, China proper, and Japan, as also to Persia, Asia Minor, and the Caucasus. In South America it occurs in the Argentine Republic and Chile; it also reäppears in the state of Honduras and in Mexico, both in the central part and also in Sonora along the Rio Grande. From the last-named locality, and probably as an eastern extension of the same area, we find it occupying the great arid plains of Arizona and New Mexico—the Shinárump formation of Powell. It again comes forth along the Atlantic slope in the Connecticut valley, in New Jersey, Pennsylvania and Maryland, and on southward through the coal fields of Virginia and North Carolina. In Europe it is this same great Mesozoic flora which has been so abundantly exhumed and brought to light in Franconia (Bavaria), in Brunswick, in southern Sweden, and in many parts of France, while to it also belong the celebrated upper Triassic beds of Raibl in Carinthia, of Lunz in Austria, of Stuttgart in Würtemberg, and of Neue Welt near Basle in Switzerland. However much these floras may differ specifically, they all have the same general facies, and bear evidence of having descended with modification from the original *Glossopteris* flora of Carboniferous age, which must then have covered land areas in the far south much greater than those of the present day.

This paper will be published in the *American Naturalist*.

The following paper was then read:

THERMOMETAMORPHISM IN IGNEOUS ROCKS.

BY ALFRED HARKER, M. A., F. G. S., OF ST. JOHN'S COLLEGE, CAMBRIDGE, ENGLAND.

The metamorphic effects due to the heat of intruded masses have, from the days of Hutton, received a fair share of attention from geologists, and as regards the phenomena thus induced in various types of sedimentary rocks we are now in possession of a considerable array of facts. Observations on the thermometamorphism of igneous rocks and of crystalline schists are, however, very few, despite the fact that any such investigation might be expected to throw light on some problems prominent in modern geology. So far as the crystalline schists are concerned, indeed, the field is almost unbroken, though such researches as those of Professor G. H. Williams in the Cortland district and of Salomon in the Adamello range have shown it to be a very promising one. In this place I confine myself to some of the facts already ascertained with regard to thermometamorphism in normal igneous rocks.

The earliest contribution of importance is that of Allport,* who drew attention to the uralitization of the augite in the "greenstones" adjacent to granite intrusions in Cornwall. Lossen † described similar effects in the diabases of the Harz, and more recently Dalmar,‡ Sauer,§ and Beck ‖ have found diabases converted into actinolite and anthophyllite schists around the syenite of Meissen, etc, in Saxony. All these observations refer to the modifications set up in one family of rocks. Barrois' ¶ "diorites," metamorphosed by the Rostrénan granite in Brittany, appear also to have been originally pyroxenic rocks, though the uralitization is not entirely confined to the vicinity of the contact. In the diabases and diorites of the Mâconnais and Beaujolais, metamorphosed by irruptions of microgranulite, Michel Lévy ** has described somewhat different phenomena, including the "epigenesis of labradorite crystals by the microgranulitic magma." So far the acid irruptives have received no notice, and the same may be said, except for a few remarks by Judd,†† of the whole of the volcanic division. It is with the last-named rocks that I propose to deal in this communication.

For a study of thermometamorphism in volcanic rocks there can be no more instructive field than the English Lake district. All the central part of that district is occupied by a great volcanic series of Ordovician age, consisting of both lavas and fragmental accumulations; and at certain places on the edge of the district these rocks all come within the metamorphosing influence of large igneous intrusions.

The lavas belong to three distinct petrographic groups, presenting, despite their geological antiquity, all the characteristics of the volcanic *habitus*—the fluxional arrangement of their elements, the vesicular structure, the development of porphyritic crystals, and (subject to secondary modifications) the isotropic residue. There

* Quart. Journ. Geol. Soc., vol. xxxii, 1876, p. 418.

† Erläut. zur geol. Specialk. Preuss., Blatt Harzgerode, 1882, pp. 79, etc.

‡ Erlaüt. zur Specialk. Königr. Sachsen, Section Tanneberg, 1889, Blatt 64.

§ *Ibid.* Section Meissen, 1889, Blatt 48.

‖ Zeits. deuts. geol. Ges., vol. xliii, 1891, p. 257.

¶ Ann. Soc. Géol. Nord, vol. xii, 1885, p. 102.

** Bull. Soc. Géol. Fr., ser. 3, vol. xi, 1883, p. 296.

†† Quart. Journ. Geol. Soc., vol. xlvi, 1890, p. 370.

are (1) *basic* lavas (hypersthene-basalts) with about 51 per cent of silica, characterized by basic feldspars, hypersthene, and iron ores, but without olivine; (2) *intermediate* lavas (pyroxene-andesites) with 59 per cent of silica, some containing a monoclinic, some a rhombic pyroxene, and some both; (3) *acid* lavas (rhyolites) with 75 per cent of silica, showing various phases of the glassy type, with feeble porphyritic development and a strong tendency to microspherulitic and macrospherulitic structures. These acid lavas, in which the ferromagnesian minerals are almost completely wanting, bear a close resemblance to certain American Tertiary rhyolites, such as those described by Mr. Whitman Cross from Custer county, Colorado; and the other types of Lake district lavas are not difficult to parallel among the newer volcanic rocks of the United States and central Europe.

The fragmental igneous rocks of the English Lake district, varying from fine submarine ashes to coarser breccias and agglomerates, are associated with each of the three groups of lavas. Those belonging to the acid group are chemically similar to the rhyolites themselves, and are not always easily distinguished from them in the field. The ashes and breccias associated with the intermediate and basic groups are often more acid than the lavas, owing to the inclusion of numerous rhyolite fragments. All the fragmental rocks, though of subaqueous formation, are in general of purely volcanic origin; but some of the rhyolitic ashes and breccias in the upper part of the series (which passes up into the Coniston limestone group) contain a variable admixture of foreign material, both detrital and calcareous.

On the western side of the district the volcanic rocks are in contact with extensive intruded masses—the granophyre of Buttermere and Ennerdale and the granite (often granophyric also) of Wastdale and Eskdale,—and extreme metamorphism has been set up. The same phenomena are presented in equal variety and with greater clearness in the neighborhood of the granite of Shap fell on the eastern edge of the district. Here, too, ordinary sediments, calcareous, argillaceous and arenaceous, come within the same metamorphosing influence, and afford a standard of comparison for the effects produced in the volcanic rocks. It may be remarked, also, that the district offers an admirable field for the study of dynamometamorphism in the same rocks and for comparison of the two lines of modification which, as here developed, give rise to widely different phenomena. The Shap fell tract in particular has been carefully examined by Mr. J. E. Marr and myself. Details of field-work and chemical and microscopic study would be out of place here, and have been recently published elsewhere;* but the results give occasion for some remarks bearing on thermometamorphism as a whole, and thus possessing a general interest.

The metamorphic aureola of Shap fell extends for about three-quarters of a mile from the visible granite outcrop, and this distance is nearly the same whether we take it in the volcanics or in any of the sedimentary groups. In this connection, however, it should be noted that the volcanic rocks had undergone considerable alteration by meteoric agencies prior to the intrusion of the granite, which took place in post-Silurian times. Such evidence as we have goes to show that fresh volcanic rocks would be less readily affected by thermometamorphism. At the outer edge of the aureola it is only the decomposition products of the intermediate and basic rocks that have been transformed; similarly in the sedimentaries it is the calcite, carbonaceous matter, etc. The general rule seems to be that the sub-

---

*Quart. Journ. Geol. Soc., vol. xlvii, 1891, p. 266.

stances most susceptible to thermal agency are those formed under ordinary meteoric conditions, minerals of direct igneous origin being more refractory.

The outer limit of the aureola, as defined by the production of new minerals undoubtedly due to the metamorphism, is fairly well defined. From there to the granite contact the metamorphism increases progressively, affecting at last all the constituents of the rocks, so that near the granite they are, with special exceptions, completely reconstituted. The changes in character from the outer to the inner limit are so gradual as to render futile any attempt to divide the aureola into successive distinct zones. The boundary against the granite is always a perfectly sharp one.

An important problem in connection with thermometamorphism is how far, if at all, are the transformed rocks altered in total chemical composition. It would be rash to give a general answer to this question without much more extensive chemical researches than any yet undertaken ; but there are some facts which throw light on the subject. It is worth remarking, too, that for this purpose igneous rocks present advantages over sedimentary, in virtue of their more homogeneous nature. It is not safe to assume that a mass of slates was originally of one chemical composition throughout, but this difficulty scarcely arises when we can trace a lava flow from beyond the limit of the aureola up to its contact with the intrusive rock. The rocks examined decidedly favor the view that thermal metamorphism is not *in general* accompanied by any change in bulk analysis. Two exceptions must be recognized. The first consists in the elimination of the volatile constituents of the rocks metamorphosed, viz, water and carbonic acid. The loss of the water, however, does not seem to be complete, hydrous minerals, such as certain micas, often occurring in highly metamorphosed rocks ; while the expulsion of the carbonic acid depends on the presence of silica, free or combined, to take its place, for we find that such expulsion does not operate in the case of a pure limestone. The second exception to the rule consists in the introduction in some cases of certain volatile constituents, such as fluorine and boric acid, and must be referred to the "mineralizing agents" on which some French geologists have laid stress as necessary concomitants of an acid intrusion. There is, however, but little trace of these among the Lake district rocks. Tourmaline occurs very sparingly at Shap fell, always close to the granite and always in immediate connection with old joint planes or other fissures, and muscovite is found mostly under similar conditions. Axinite and fluorite are not known.

In some described cases of thermometamorphism it has been considered that the altered rocks have, in the neighborhood of the contact, received an accession of silica derived from the invading magma. No such process can be verified in the Lake district. Some of the rocks, and especially the rhyolitic lavas and ashes, have undoubtedly been impregnated with silica, and a similar feature is not uncommon in the acid lavas of northern Wales and other districts. The silica is sometimes seen, in slices, to have replaced feldspar crystals, and the abnormally high silica percentage in some analyses of old rhyolites must be explained by some such secondary action. But the phenomenon in question has clearly no relation to subsequent igneous intrusions, occurring, as it does, often in places far remote from any intruded mass. Whether due to ordinary meteoric weathering or, as seems probable, to solfataric action not long posterior to the cessation of vulcanicity, this silicification cannot be referred to any cause properly described as thermometamorphism.

In the metamorphism characteristic of the Lake district, the chemical changes involved in the production of the new minerals are of various degrees of complexity. There may be simple paramorphism, as when chalcedonic silica filling cracks in the lavas is converted into crystalline quartz, still retaining in some cases its characteristic mammillary structure. There may be mere dehydration, as perhaps in the almost universal formation of brown mica from the chloritic decomposition products of pyroxene, etc. To convert a substance of the nature of delessite into biotite would require little more than the elimination of most of the water. Such changes as these are found to be among the earliest results of the metamorphic action. Again, part of the new-formed feldspar in the altered volcanics seems to arise from the regeneration of original feldspar. This is well seen in the porphyritic crystals in the lavas and in those scattered through some of the ashes, the old turbid feldspar substance being replaced, partially or wholly, by new pellucid material; but the pseudomorphs no longer consist of single individuals, and one cannot positively assert that they are chemically identical with the original feldspar. The other new-formed minerals for the most part indicate atomic rearrangements of a more complex order.

The minerals generated in the metamorphism of the volcanic rocks are numerous, at least in the basic and intermediate groups. Most important in the list are quartz; various feldspars; biotite and allie dmicas; green hornblende, actinolite and tremolite; a lime-augite; sphene, rutile and ilmenite; magnetite, pyrite and pyrrhotite.

In all the volcanic rocks in their most highly metamorphosed state a large proportion of the bulk is found to consist of feldspars, among which are recognized orthoclase, albite, anorthite, and some of the intermediate varieties. With this constant abundance of new-formed feldspars we may correlate the absence or rarity of certain aluminous silicates, such as garnet, andalusite, staurolite, etc, known as common metamorphic minerals in many sedimentary rocks. Cyanite and andalusite occur only occasionally in some of our metamorphosed ashes, and the garnets are entirely wanting. Such minerals will naturally arise in the metamorphism of rocks impoverished in alkalies by the ordinary processes of chemical degradation; and, in contradistinction to these, the abundant formation of feldspars may be expected to characterize the alteration of rocks of direct igneous origin. Feldspars, however, are certainly formed in many metamorphosed sedimentaries, either in addition to andalusite, etc, or to the exclusion of such minerals whenever the original material contained sufficient alkalies. The metamorphism of certain flags near the Shap granite has given rise to abundant feldspars, while garnet and chiastolite are absent and andalusite is certainly not characteristic. So far as our data go, this seems to be a more common thing in the older than in the newer sediments. Broadly speaking, we may expect the newer detrital rocks, in so far as they are derived from older sedimentaries, to become increasingly poor in alkalies.*. The apparent reluctance of some geologists to admit feldspar as a highly characteristic product of extreme thermometamorphism may be due to the fact that the minuteness of the grains in most cases, the rarity of twinning, and the singular clearness of the mineral make it often easily mistaken for quartz. It is instructive to compare the ultimate destruction of the feldspars in extreme dynamometamorphism.

---

*Taking at random the analyses of "Thonschiefer" given by Roth, rejecting only those cases in which the stratigraphy is known to be at fault, I find that twenty-one examples grouped under "Silur" give average percentages 3.864 of potash and 1.226 of soda; twenty-seven under "Devon" and "Culm" give 2.701 of potash and 0.973 of soda.

A brown mica referred to biotite has been formed abundantly in many of the rocks studied: sometimes directly from augite, more often from the decomposition products of that mineral and the feldspars. Besides the flocculent clusters of scales occupying the place of vanished pyroxene, there are often minute flakes of biotite scattered through the regenerated feldspars alluded to above. In spots where more lime was present, as, for instance, within the vesicles of the lavas and in certain little veins which must have been occupied in part by calcite, green hornblende occurs instead of biotite; and some little veins, more calcareous than the others, are converted instead into a granular monoclinic pyroxene. This pyroxene must, from chemical considerations, be one rich in alumina as well as lime—an omphacite rather than a diopside. The distribution of these various minerals in the metamorphosed volcanics is a good illustration of the way in which the products formed at any point depend on the chemical composition of the mass in the immediate neighborhood of that point. Prior to metamorphism certain substances were uniformly distributed through the rock, while others, owing in great measure to weathering action, were concentrated in particular spots; from this results in part the wide variety of secondary minerals frequently met with.

The titaniferous minerals afford another instructive example. Titanic acid in some form seems to have been pretty uniformly distributed through many of these old volcanic rocks. In the metamorphosed products it is for the most part taken up by the mica (typical biotite containing nearly 5 per cent. of titanic acid); but where there has been sufficient lime to form hornblende or omphacite in place of biotite, the titanic acid appears as sphene; where iron oxides were present in some abundance we find ilmenite; and again, in some of the rhyolitic ashes very poor in lime and iron, simple rutile occurs. Such facts certainly point to the conclusion that in the processes of thermometamorphism there is very little interchange of substance except between closely adjacent points.

Of some significance in this connection is the constant preservation of the former structures of the rocks, despite extreme metamorphism of their material. The ovoid vesicles of the andesites, filled previous to the granitic intrusion by the ordinary weathering products, are still perfectly distinct even in the most highly metamorphosed examples. The flow-structures of the lavas and the lamination of the ashes, whenever they were distinctly pronounced, have been well preserved, being often emphasized by a certain foliation due to the parallelism of biotite flakes, and then indistinguishable from typical micaschists or microgneisses. In places where the rocks have been cleaved before metamorphosis, this foliation follows the cleavage. The macrospherulites in the rhyolites have at an early date undergone changes common in the older acid lavas, giving rise to a segregation of different materials in alternating concentric shells, and this structure is beautifully retained in the metamorphosed examples, the several distinct shells giving rise to different secondary products, and the concentric partings being defined by special minerals due to "agents minéralisateurs." A calcareous breccia overlying these acid lavas contains angular fragments of rhyolite, and these, even close to the granite, retain their micro-spherulitic and other structures, besides a system of minute perlitic cracks now occupied by little veins of pyroxene which clearly represent calcareous infiltrations from the matrix of the breccia. Such striking instances of the preservation of minute structures negative the idea of any considerable interchange of material between different parts of the rocks affected, and by implication suggest

that the total chemical composition of the rocks has remained substantially the same during the metamorphic processes.

All these metamorphosed rocks, though dating from pre-Carboniferous and probably early Devonian times, present a remarkable freshness of aspect in all their constituent minerals. This is very noticeable in thin slices cut to show the junction of the granite with the volcanics, the feldspars and biotite of the former rock having all the usual signs of weathering decomposition, while the same minerals in the metamorphosed rocks retain unimpaired their pristine clearness. This immunity from weathering action appears to be a characteristic feature of metamorphic products, whether formed by thermal or by dynamic agencies, but I have not met with any attempt to frame a general explanation of it.

So far I have treated the metamorphosed volcanics as a whole, without distinction of the three groups. In the basic and intermediate groups of lavas the changes produced follow very closely the same lines. The original mineralogical differences between the two groups lay chiefly in the relative proportions of their several constituents and in the nature of the feldspars, and the metamorphosed representatives do not show any more essential difference. All the foregoing remarks apply to both groups alike, and apply to the fragmental as well as to the fluidal members. In the inner part of the aureola, indeed, the ashes have to be distinguished from the lavas by structural rather than mineralogical characters.

The acid rocks present a different set of phenomena. In the vicinity of the granite they often consist of an exceedingly fine grained aggregate of clear feldspars and quartz. From this we might suppose that the metamorphism has induced crystallization in rocks originally largely glassy or with special structures not far removed from the vitreous; but such an inference would not be warranted. In other places we find examples which show little or no evidence of any alteration at all. For instance, I have already mentioned rhyolite fragments in a highly metamorphosed breccia, which still retain in perfection their micro-spherulitic structure. This is a case in which the visible structure is so intimately bound up with the molecular that one can scarcely imagine a rearrangement of the latter while the former remains uneffaced, and we are almost driven to the conclusion that the fragments are practically in their original condition. This slight susceptibility to thermometamorphism is perhaps to be correlated with the simple chemical composition of our rhyolites, which contain very little iron or lime and no magnesia, so that they have little more than the elements of acid feldspars and quartz. The evident alteration of some of the rocks, on the other hand, may be referable only in part or not at all to thermal metamorphism connected with the intrusion; for, as already noticed, these rocks have often been affected by earlier changes both physical (devitrification) and chemical (silicification). The ashes associated with the Lake district rhyolites have behaved, as a rule, in a precisely similar manner; but at some horizons, where a certain amount of magnesia and iron oxides was present, we find to a limited extent the same production of biotite, etc., that characterizes the metamorphosed andesitic ashes. It is evident that in the fragmental volcanic rocks, with their heterogeneous constitution, we cannot expect the chemical grouping into acid, intermediate, basic, to hold so exactly as in the lavas. It should be noted, as a further point of interest, that the rhyolitic ashes have been more decomposed than the corresponding lavas prior to metamorphism, and the consequent loss of alkalies has caused andalusite and cyanite to be formed among the metamorphic products in place of the usual feldspars, though only to a limited extent.

Summarily, the chief results as regards the thermometamorphism of volcanic rocks in the English Lake district are as follows:

1. Basic and intermediate lavas and ashes, especially when affected to any extent by weathering processes, are as readily metamorphosed by heat as are argillaceous sediments. Acid lavas and ashes of simple chemical composition may, however, be very little modified, even by a very high temperature.

2. Feldspars of various kinds, formed sometimes by the rejuvenation of old feldspars, sometimes by recombinations from other minerals, are universally present in abundance among the new-formed products in the advanced stages of metamorphism. Andalusite, garnet, and some other aluminous silicates common in metamorphosed sedimentary rocks are, as a rule, absent.

3. The characteristic ferromagnesian minerals generated are biotite and green hornblende, augite being exceptional; and the formation of one or other of the three minerals depends especially upon the percentage of lime in the material metamorphosed.

4. The only changes in the total composition of the rocks of which we have any evidence in this district are those occasioned by a loss of water and carbonic acid, and rarely and to a limited extent by an accession of hydrofluoric and boric acids.

I remarked at the outset that investigations into the effects of thermometamorphism may be expected to throw some light on problems connected with the origin of crystalline schists. The suggestion cannot be properly developed in this place. It may be pointed out, however, that the post-Silurian intrusions of the Lake district, including those of Shap fell and Eskdale, can clearly be referred to the great crust movements which there brought the Silurian period to a close, and which impressed on the whole district its peculiar geological structure. The effects of the lateral thrusts which then operated did not there reach anything like the intensity displayed in the region of the Scottish Highlands, but they furnish, perhaps on that account, an instructive study. Had the mountain-making processes progressed in the Lake district to the same stage as in northern Scotland, we should have dynamic superimposed on thermal metamorphism in the petrographic complex formed by the great intrusions, in their minor off-shoots, and in the adjacent altered rocks, but the results of the thermometamorphism would still remain as a factor in the final product.*

The paper was discussed by A. C. Lane, Thomas Macfarlane, of Ottawa, Canada, C. R. Van Hise, and the author.

After announcements from the chair, Mr. J. F. Kemp, of the Committee on Photographs, announced that the suite of photographs collected by the committee was on exhibition in the Library of the University.

The Society then took a recess until 2 o'clock p. m.

* Marr: Quart. Journ. Geol. Soc., vol. xlvii, 1891, p. 328.

Afternoon Session, August 24.

The Society reassembled at 2:20 p. m.

The first paper read was:

THE LOWER SILURIAN (ORDOVICIAN) ICHTHYIC FAUNA AND ITS MODE OF OCCURRENCE.

BY C. D. WALCOTT.

This paper was dicussed by Dr. Friedrich Schmidt, Professor E. W. Claypole, Professor E. D. Cope, Dr. Karl von Zittel, Dr. Otto Jaekel, and the author. It is printed elsewhere in this volume.

The following paper was then read:

THE PLANT-BEARING DEPOSITS OF THE AMERICAN TRIAS.

BY LESTER F. WARD.

Contents.

Introduction.

Having been requested by the Director of the United States Geological Survey to prepare an essay on the correlation of the American plant-bearing deposits of the United States, so far as indicated by their respective floras, I entered upon this work in February, 1888, and have continued it as opportunity permitted to the present time. The formations were taken up in their order of succession, beginning with the lowest, and the treatment of the Paleozoic horizons was completed, subject to revision, in July, 1889. The Trias was then taken up and brought to a conclusion near the end of 1890. The next higher Mesozoic floras are now in hand.

The plan of treatment has been to give first a historical account of the discovery of vegetable remains in each formation, followed by such citations of opinion relative to its age as will show the progress hitherto made in fixing its geological position, and then to compile and discuss the paleontological data, and make thorough comparisons of each flora and florule with all others that contain the same or similar vegetable forms.

In the present paper I shall confine myself to the Triassic deposits of the United States, as having an especial interest from this point of view: first, because their precise age has been much discussed and has not been definitely settled; and secondly, because the paleontological data, meager in all departments, consist so largely of fossil plants.

The lower members of the Trias corresponding to the Buntersandstein and Muschelkalk of Europe, if present at all in the United States, are not believed to have furnished any of the fossil plants that are referred to that system. In fact, although the Triassic beds of this country have in some places a great thickness, and although there are indications that those of certain localities occupy a somewhat different position from those of others, still, taking all the evidence into the account, it seems probable that not only all the plant-bearing strata, but also all the rocks which are known as Triassic within the limits of the United States, belong near the top of the system and represent the upper Keuper, or perhaps the uppermost of them may correspond to the Rhetic of the Old World nomenclature.

As the true Permian is scarcely found within our borders, it will be perceived that between our rich plant-bearing Carboniferous formation and the next higher deposits carrying vegetable remains a wide chasm exists, measured by an immense period of time. It is therefore not to be expected that any traces of the Paleozoic flora will be found in the comparatively recent deposits of the upper Trias. Such, indeed, is the case, so far as we now know these floras, and we have to regard these later deposits as the beginning of a new era in the history of plant life.

It is true that Rogers, Bunbury and others of the earlier authors who described the fossil plants of the Richmond coal field supposed that they had found specimens of *Lepidodendron*, *Sigillaria* and *Calamites*; but it is now known that this is not the case; that the supposed lepidophytes belong to the coniferæ, and that the alleged *Calamites* was a gigantic *Equisetum*. Specimens of this last were sent to Brongniart, and it was upon his authority that they were referred to *Calamites* (*C. suckowii*); but Brongniart himself expressed doubts in regard to their relation to Calamites, and it may be worth our while to hear what he says on that point. He made the American specimen to constitute a variety of that species, and on this he remarks as follows:

"La var. dont la surface externe est assez mal conservée, se rapporte cependant à cette espèce par sa forme générale et par la ténuité de l'écorce. Les côtes sont seulement plus convexes, ce qui peut tenir à une moindre compression; car ces tiges, qui étaient probablement verticales, paraissent avoir été comprimées dans le sens de leur longueur, et présentent des replis nombreux qui semblent indiquer combien leurs parois étaient minces et flexibles. Cet échantillon est même fort remarquable sous ce rapport, et prouve que ces tiges étaient fistuleuses comme celles des *Equisetum* vivans." *

This species, which is the *Equisetum rogersi* of Fontaine, perhaps comes the nearest to the connecting link between the Carboniferous and the Mesozoic of all the American forms, but there is no doubt of its generic distinctness from *Calamites*. It is possible that when the palissyas and other conifers of the Trias are better known a close relationship will be found to exist between them and some of the allied strictly Permian conifers; but upon this no important conclusions can now be based. The Triassic flora is also found to be almost as completely cut off from the floras that are known in the United States above that horizon as they are from those below it. If any distinctly Jurassic strata exist within our borders they are not as yet known to carry fossil plants, and the next higher horizon at which these are found is that of the Potomac formation of Virginia and Maryland, or the perhaps equivalent Kootanie deposits of the great falls of the Missouri and the Trinity division of Texas. These, appearing to be nearly of the same age, ought all to belong to the lower Cretaceous.

---

* Histoire des Végétaux fossiles, vol. i, 1828, p. 126.

The flora of the Kootanie and the Trinity is very little known, but the Potomac formation has furnished an abundance of vegetable remains; yet, no single species of the Trias is found to occur in that formation. There are, however, six species in the Potomac flora which resemble those of the Trias sufficiently to admit of comparison. Of these, three are ferns, two are cycads, and the remaining one is a *Sagenopteris*. As the local habitat of these species was nearly the same at the two epochs, there is considerable probability that the Potomac plants may have been the direct descendants of those of the Trias.

Still, to all intents and purposes, the Triassic flora of the United States may be regarded as a distinct and independent flora. So considering it, there are two points of view from which it can be treated when studying more especially the question of its age: We may inquire first whether it constitutes one homogeneous flora, or whether the different parts bear evidence of having been deposited at considerably different periods of time. In the second place, we may inquire what its relations are to other known floras of the globe—in other words, when treating of the species of fossil plants found in this group, we naturally concern ourselves, first, with their American distribution, and secondly, with their foreign distribution.

American Distribution.

I have divided the American plant-bearing Trias into five distinct geographical areas, corresponding nearly with so many geological basins:

First, that of the Connecticut valley, so long known to geologists from the discovery in it of the tracks of animals. In this I assume the Southbury area, though isolated geographically, to be included.

Second, the New Jersey and Pennsylvania area, extending from the Hudson river to the Potomac. I have not used the term "palisade area," which was employed by Professor Dana, because he makes this to include also the Triassic deposits of Virginia, and even to embrace the Richmond coal field. It would be logical, it is true, to make this embrace the Piedmont deposits, extending as far south as Charlottesville, in Virginia. Between this and the Virginia coal field there is a complete interruption as great as that between the Connecticut valley and the palisades. As all these areas may have once been confluent, it is not considered important to maintain their strict geological relationships.

Third, the Virginia area which I make to include all the deposits in that state, those of the Richmond coal field having furnished nearly all the fossil plants.

Fourth, the North Carolina basins or areas, including the North Carolina coal field. The deposits in this state are not continuous, but consist of several isolated basins.

Fifth, the Western area. This includes all the deposits in Arizona and New Mexico, and also in Colorado and other adjoining states and territories where known, and constitutes the Shinárump formation of Powell. Fossil plants other than silicified wood have been found only in New Mexico in the vicinity of Abiquiu and the copper mines. Silicified wood is found strewn about upon the plains in vast profusion wherever the formation exists.

Keeping in view these five basins, it is necessary first to eliminate all the forms which are confined to any one basin. We find that out of a total of 119 species belonging to the American Trias, 33 occur in the Connecticut valley, 18 in New Jersey and Pennsylvania, 56 in Virginia (including the single species found in

Maryland), 52 in North Carolina, and 13 in New Mexico and Arizona. Of course, many of these species occur in more than one of these areas, the extent of the overlapping amounting to 43 species, or a little over one-third. We thus learn that 85 of the 119 species, or considerably over two-thirds, are confined to one basin—in fact, to one state or territory. So far, therefore, as the question of distribution or parallelism within the United States is concerned, these 85 species are of no value, and our present discussion must be confined to the remaining 34 species which are found in two or more of these localities.

Considering these 34 species, we find that there are common to the Connecticut valley and to the New Jersey and Pennsylvania area, 5 species; to the Connecticut valley and the Virginia basin, 5 species; to the Connecticut valley and North Carolina basin, 6 species; to the Connecticut valley and great Western basin, 1 species; to the New Jersey and Pennsylvania area and the Virginia basin, 7 species; to the New Jersey and Pennsylvania area and the North Carolina basin, 10 species; to the New Jersey and Pennsylvania area and the great Western basin, 2 species; to the Virginia and North Carolina basins, 20 species; to the Virginia and Great Western basins, 2 species; to the North Carolina and great Western basins, 2 species.

These facts may be expressed in tabular form as follows:

Areas.	Areas.			
	New Jersey and Pennsylvania.	Virginia.	North Carolina.	New Mexico and Arizona.
Connecticut valley	5	5	6	1
New Jersey and Pennsylvania		7	10	2
Virginia			20	2
North Carolina				2

If, in order to avoid the repetition of the names, we number the basins from north to south, that of the Connecticut valley being 1; New Jersey and Pennsylvania, 2; the Richmond coal-field, 3; the North Carolina basin, 4; and that of the far west, 5: then we observe that there occur in the first, second and third basins 1 species; in the first, third and fourth basins, 1 species; in the second, third and fourth basins, 3 species; in the first, second, third and fourth basins, 1 species; in the second, third, fourth and fifth basins, 1 species, and in all of the five basins, 1 species. This last is the widely diffused *Cheirolepis münsteri*.

There has been no serious question as to the parallelism of the New-Jersey and Connecticut valley deposits, and as only eight unsatisfactorily determined species occur in Pennsylvania it is impossible to argue from so meager data. Again, the

fact that twenty species are common to the Richmond coal field and that of North Carolina argues very strongly for the near parallelism of these deposits. The principal problem, then, is whether the Connecticut valley basin and the New Jersey area are really of the same or nearly the same age as the coal-beds of Virginia and North Carolina. The five species common to the Connecticut valley and Virginia, and the six species common to the Connecticut valley and North Carolina weigh for all they are worth directly upon this problem. With regard to the New Mexican beds, we find that out of the thirteen species there found, only two occur also in the east. These are the wide-spread forms *Cheirolepis münsteri* and *Palissya braunii*, which have been found in both the northern and southern basins.

Notwithstanding the thoroughness of this analysis, it nevertheless leaves the mind in a somewhat unsettled condition with regard to the main question as to whether the data sustain the view that these different deposits are really shown by the fossil plants to occupy about the same horizon or to have been laid down at about the same epoch. This is chiefly due to the great difference in the extent to which the different basins are represented by the fossil plants, especially to the relative meagerness of the flora of the Connecticut valley and New Jersey as well as that of the west as compared with the abundant flora of the Virginia and North Carolina basins. The problem is, therefore, to eliminate this element of obscurity and to reduce all the basins to some common basis of comparison. This can only be done by the use of percentages. For example, it will be instructive and will be the best that we can do to show what per centage of each florule—that is, of the plants of each distinct basin—is also found in any of the other basins. For this purpose we may take the gross number of species or forms that occur in each basin regardless of overlapping. From this gross number we may deduct all those that are confined to each basin, the remainder being common to it and some other basin. Then calculating the percentage of these common forms to the total number occurring in each basin, we shall not only have a clear idea of the relation of each florule to the American Trias taken together, but also of the relative homogeneity of all the florules.

The following table will show this:

Basins or areas.	Occurring in—	Confined to—	Common to, and some other basin.	Per cent in other basins.
Connecticut valley	23	13	9	39
New Jersey and Pennsylvania	18	5	13	72
Virginia and Maryland	56	34	22	39
North Carolina	52	25	27	52
New Mexico and Arizona	13	11	2	15

From this table it appears that none of the basins except that of the west contains less than 39 per cent of common species, and that one of the basins, viz, that

of New Jersey and Pennsylvania, has 72 per cent of its plants common to other basins, while that of North Carolina has 52 per cent common. These two remarkably exceptional cases are the smallest of the five basins. Of the three principal basins, that of the Connecticut valley has 39 per cent; that of Virginia, 39 per cent; and that of North Carolina, 52 per cent of common species.

Considering that we are dealing with a fossil flora, a large number of whose forms are not specifically determinable and most of the material of which is fragmentary, the fact that in all but one of these five florules of the American Trias the number of forms sufficiently distinct to be clearly determinable specifically and to be identified with forms in other basins, ranges from 39 to 72 per cent may be taken as very strong evidence of the general parallelism of these four basins.

As regards the western deposits, notwithstanding the poverty of their present known flora, there seems to be some indication that they were not laid down at the same exact epoch as those of the Atlantic coast; but, assuming such an asynchronism, the question as to whether they are earlier or later cannot be profitably considered with the present insufficient data.

Foreign Distribution.

The foreign distribution of the Triassic flora has been a much more difficult problem, and has required a large amount of careful analysis. Five tables have been prepared with the object of exhibiting it to the fullest possible extent.* In discussing this problem all species which are entirely without foreign distribution or affinity are of course omitted. The remainder are divided into two classes: First, those which are actually found in other formations and localities than the American Trias; and second, those which, though not so found, are obviously related to other species that are. There are 40 species belonging to the first, and 17 to the second of these two classes, making 57 species which have diagnostic value in determining the age of the formation.

In the first or most extended of the tables of foreign distribution, these 57 species are introduced and the foreign distribution, both geological and geographical, is shown. The amount of detail, however, is so great that it is impossible to discuss the problem without further analysis. The first step in such analysis has been the preparation of a table from the geological point of view, giving under each formation the species which are common to it and the American Trias. In some respects this table goes still further into details than the former one, and a full explanation of many of the cases presented in it is made.

The third of the tables of foreign distribution relates exclusively to the first class above named—that is, to the American Triassic species which have a foreign distribution,—and gives each species with such distribution, only, however, as regards the geological position, leaving the geographical range to be determined by reference to the table last considered.

Finally we have a recapitulation of all the data thus far set forth showing the number of species occurring at each of the other horizons in the total distribution:

---

*Several large charts illustrating so far as possible the data contained in these tables were exhibited before the Society. These cannot conveniently be introduced here, but will appear in the final essay.

Summary of the geologic and systematic Distribution of American Triassic Plants and their Allies.

Geological formations.	Ferns.		Equiseta.		Rhizocarps.		Cycads.		Conifers.		Total.	
	Identical.	Related.	Identical.	Related.	Identical.	Related.	Identical.	Related.	Identical.	Related.	Identical.	Related.
Potomac	....	4	....	....	....	1	....	2	....	....	....	7
Wealden	....	1	....	....	....	....	....	2	....	....	....	3
Oölite	2	5	....	2	1	....	1	4	3	1	7	12
Lias	3	4	....	1	1	....	1	7	3	....	8	12
Lower Jurassic	1	....	....	1	....	....	....	....	....	....	1	1
Rhetic	3	8	1	2	1	....	5	6	4	1	14	17
Triassic	3	5	....	1	....	....	5	3	....	....	8	9
Keuper	12	5	3	1	1	....	3	5	1	1	20	12
Muschelkalk	....	....	2	....	....	....	....	....	....	....	2	....
Buntersandstein	1	....	1	1	....	....	....	1	1	....	3	2

In this table the classification of the several types of vegetable life has been introduced. It will be seen that there are represented among the plants that have a foreign distribution ferns, Equiseta, rhizocarps, cycads and conifers. Considering the geological range, we observe that it extends from the Buntersandstein to the Potomac formation or lower Cretaceous; but if we scan the columns closely we perceive that none of our species actually occur above the Oölite, the only forms here compared in the Wealden and Potomac being forms allied to American Triassic species. On the other hand, it is remarkable that the largest number of identical forms occurs in the Keuper. This results from the very large number that Dr. Stur has identified with the plants of the Keuper of Lunz, Austria, and those of Raibl, in Carinthia, and of certain localities in Switzerland, referred to about the same age.

I have summed up the general results of my investigation of the American Triassic flora both from the geological and botanical standpoints in the final table (page 30), to which I now call attention.

We perceive by inspection of this table that the flora consists of 119 specific forms, which may for convenience be called species, though many of them are not specifically determinable and in a few cases they consist of varieties. These 119 species belong to 51 genera, although of the 51 a few are not distinctly named as genera and some may be merely the fruit of the same genera that are also found in other forms.

Looking to the botanical affinities of these forms, we find that the most of them can be classified under some of the general grand divisions of the vegetable kingdom, although in a few cases this determination is very uncertain. We thus have what seem to be representatives of eight great types of vegetation. These types, beginning with the lowest and naming them in the supposed ascending order of their structure, are, first, fucoids, that is some kind of seaweed; second, ferns; third, equiseta; fourth, lycopods; fifth, rhizocarps; sixth, cycads; seventh, conifers; and, eighth, monocotyledons. There remain five genera and six species whose botanical affinities are wholly unknown.

General Elements of the American Triassic Flora.

Classification of genera and species.	Fucoids.	Ferns.	Equiseta.	Lycopods.	Rhizocarps.	Cycads.	Conifers.	Monocotyledons.	Plants of unknown affinity.	Total.
Number of genera occurring in the American Trias..........	5	15	2	1	1	12	8	2	5	51
" " species " " " "	9	35	11	1	1	35	19	2	6	119
" " " confined to the " "	9	18	7	1	......	22	14	2	6	79
" " " not confined to the " "	......	17	4	......	1	13	5	......	......	40
" " " confined to the American Trias, yet related to species of other formations and localities..............	......	7	2	......	......	7	1	......	......	17
" " " either not confined to the American Trias or related to species not found in it; therefore having diagnostic value in determining its age......................	......	24	6	......	1	......	20	6	......	57
" " " not only confined to the American Trias, but without relation to species not found in it; therefore without diagnostic value in determining its age.................	9	11	5	1	......	15	13	2	6	62

Keeping this botanical classification in view, we may next look at this flora from the point of view of its geological importance, that is, of ascertaining how many of these forms have any diagnostic value for geology. To determine this we need to know the number of forms that are not confined to the American Trias but are found in other formations and at other localities—forms that have a geological and geographical distribution. The table shows that only 40 of these forms have such a distribution, viz, 17 ferns, 4 equiseta, 1 rhizocarp, 13 cycads, and 5 conifers. But there is another class which has also a diagnostic value, viz, those species which, having no distribution of their own, are clearly shown to be allied or related closely to other plants occurring in other formations and localities. Of these there are 17, viz, 7 ferns, 2 equiseta, 7 cycads, and 1 conifer. Putting these two elements together, we have 57 diagnostic species, viz, 24 ferns, 6 equiseta, 1 rhizocarp, 20 cycads, and 6 conifers. This leaves 62 species, or over 52 per cent, not found in any other formation and not allied to any species known elsewhere; therefore without diagnostic value.

GENERAL CONCLUSIONS FROM FOREIGN DISTRIBUTION.

It will be seen that tables three to six, inclusive, relate to the foreign distribution of the fifty-seven diagnostic species, and it may now be inquired in general terms what is the final outcome of these extended comparisons. Do they serve in any sense to correlate the American Trias with any of the Old World deposits? If the answer is that they do not enable us to say with positive certainty that the American deposits are exactly parallel with any others, this is a very different thing from saying that the facts thus presented are worthless, or that they do not greatly increase our knowledge of the position which they occupy in the geological scale.

It must be remembered that it is chiefly from the plants that we derive this knowledge. All discussions of the animal remains, even the abundant ichnites of the Connecticut valley, left their age enshrouded in doubt. Early mistakes in determining the vegetable remains caused opinion to fluctuate all the way from the Oölite to the Carboniferous. The present accurate knowledge fixes the horizon with almost absolute certainty at the summit of the Triassic system, and narrows the discussion down chiefly to the mere verbal question whether it shall be called Rhetic or Keuper. At present, as we saw in the detailed consideration of the facts brought out by the fourth table, the beds that seem to be most nearly identical, so far as the plants are concerned, are those of Lunz, in Austria, and of Neue Welt, near Basle, in Switzerland. These have been placed by the best European geologists in the upper Keuper. Our American Trias can scarcely be lower than this, and it probably cannot be higher than the Rhetic beds of Bavaria.

In the discussion following the reading of the paper, Mr. G. K. Gilbert remarked that the four eastern provinces are more closely related by their floras than any one of them is related to the one western province, and that the same conclusions were reached by a consideration of the purely physical features of these provinces.

The author of the paper said that the species of the American Trias have more affinities with the meager flora of the European Keuper than with the much more abundant flora of the Rhetic.

The next paper was entitled:

STUDIES IN PROBLEMATIC ORGANISMS—THE GENUS *SCOLITHUS.*

BY JOSEPH F. JAMES, M. S., F. G. S. A., ETC.

In 1840 Professor S. S. Haldemann described a fossil occurring in a sandstone of southeastern Pennsylvania as follows:*

"*Fucoides* (?) *linearis:* Stem simple (never branched), rectilinear, surface nearly even; diameter ⅛ to ¼ inch, length several feet, cylindrical or compressed. Locality, south of Reading and north of Columbia, Pennsylvania, being the oldest fossil in the state, occurring in the first stratified rock above the gneiss. *Obs.:* I discovered this fossil in 1835, and described it about three years ago as *Skolithos linearis*, and because the genus *Fucoides* is composed of heterogeneous materials. The characters of the sub-genus *Skolithos* are: Stem free, cylindric or sub-cylindric, vermiform or linear, never branched; structure unknown."

This is the first introduction of the name *Scolithus* into geological literature, although forms now recognized as belonging to the genus had been previously mentioned. In 1833 Professor Edward Hitchcock noticed a fossil supposed by him to be a fucoid occurring in the New Red sandstone (Triassic) of Deerfield and Greenfield, Massachusetts. He described it † as varying from $\frac{1}{10}$ to 1 inch in diameter, running through the rock either in the direction of the laminæ, when it is more or less compressed; or at right angles or obliquely to the laminæ, when it is cylindrical. It is frequently curved but never branched. A specimen broken transversely showed the cylinder to be made up of convex layers of sandstone, piled one upon the other (figure 1). On one side of the rock were button-like protuberances and on the other side corresponding cavities. It was supposed to resemble *Fucoides brongniarti*, Harlan, but no name was applied to it. In the second edition of the Geology, however, published in 1835, the same fossil is described (pp. 235, 236); and, after stating the conclusion that it differed from *Fucoides brongniarti*, Hitchcock proposed to call it *F. shepardi*. The cylindrical form passing through the laminæ of the rock seems to be congeneric with *Scolithus*, although the compressed form, parallel with the laminæ, may not be the same. The genus *Fucoides* having been broken up and abandoned, I propose that this form be called *Scolithus shepardi*. In the final report on the geology of Massachusetts, published in 1841, the fossil is again described in the same language as that previously used.‡ Two figures are also given, one of which is reproduced in figure 1 of this paper.

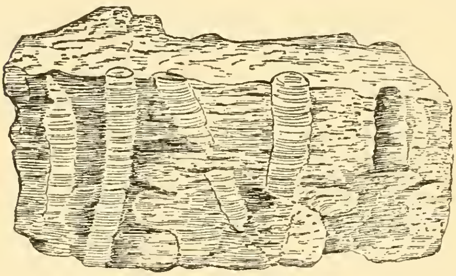


FIGURE 1—*Scolithus shepardi, Hitchcock* (*sp.*) (*After Hitchcock.*)

In 1838 Professor W. B. Rogers in describing the rocks of Formation I, as it occurred in Virginia, referred to markings at right angles to the stratification which

* Supplement to No. 1 of "A Monograph of the Limnaides or Fresh-water shells of North America." October, 1840, p. 3.

† Report on the Geology, Mineralogy, etc, of Massachusetts: Amherst, 1833, p. 233.

‡ Volume ii, pp. 455, 456; fig. 95.

were said to penetrate "in straight lines to great depths in the rocks, and from their frequency and parallelism determining its cleavage in nearly vertical planes. These markings are of a flattened cylindrical form, from $\frac{1}{8}$ to $\frac{1}{10}$ of an inch broad, giving the surface of the fractured rock a ribbed appearance, and resembling perforations in sand which have been subsequently filled up without destroying the distinctness of the original impression." Similar markings are stated to be found higher up in the series.* The form here described is now recognized as *Scolithus linearis*, Haldemann.

In 1842 Lardner Vanuxem referred to certain fucoids found in the Oneida conglomerate, near New Hartford Center, New York. He described them as smooth, cylindrical and ramose, many about $\frac{3}{4}$ of an inch in diameter, and arranged vertically in the rock.† It is possible that this form is the same as that subsequently described and illustrated by Professor Hall. Vanuxem did not, however, give the fossil any name.

In 1843 Professor James Hall ‡ illustrated *Fucoides verticalis*, stating that it consisted of small, round stems extending vertically through the strata, as if they had been growing at the time the sand was deposited around them. They are said to always characterize the upper part of the Portage group (see figure 2). Whether the same or not, a species under the name of *Scolithus verticalis* was described by Hall in 1852 as occurring in the Medina sandstone.§ If the two forms are to be considered as distinct, that from the Medina must receive a new name.‖

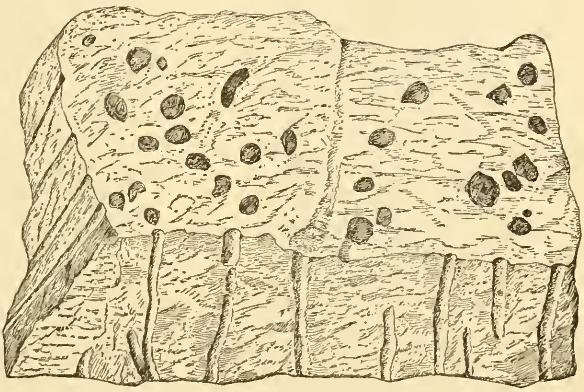


FIGURE 2—*Scolithus verticalis, Hall* (*sp.*). (*After Hall.*)

In 1847 appeared the first illustration and the second description of *Scolithus linearis.* It was by Professor Hall, in volume 1 of the Paleontology of New York, page 3. It was referred to by him as possibly a plant, though no opinion is expressed as to its affinities. He said it was "apparently confined to the Potsdam sandstone," and it occurs in the valley of Lake Champlain, near Adams, Massachusetts, in sandstone of the same age in New Jersey and Pennsylvania, "and it may be traced in the same rock through Maryland and Virginia to Tennessee." Figures are given of specimens from Adams, Massachusetts, and from Pennsylvania. Those

*Geology of the Virginias. Report of Progress of the Geol. Sur. of Virginia for 1837. Reprint edition, 1884, p. 168.

†Geology of New York, Third Geol. District, 1842, p. 76.

‡Geology of New York, Report of Fourth Geol. District, 1843, p. 242.

§Paleontology of N. Y., vol. ii, 1852, p. 6.

‖For this I would propose the name *S. clintonensis*, as there cannot be two species of similar name in the same genus.

we give below (figures 3 and 4), taken from Walcott's paper on the Olenellus fauna,* do not differ in any essential character from the figures given by Hall.

In 1851 Professor H. Goeppert published a paper on the flora of the Transition rocks,† in which he refers to *Scolithus linearis* as a plant under the name of *Scolecolithus linearis*.‡

In the following year (1852) Professor James Hall described as a new species *Scolithus verticalis*, from the Medina sandstone.§ As noted above, he had mentioned *Fucoides verticalis* from the Portage, and a comparison of the two forms fails to show

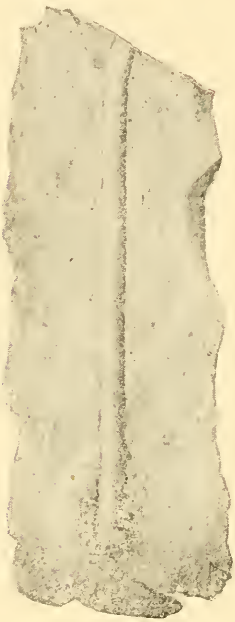


FIGURE 3—*Scolithus linearis, Haldemann.* (*After Walcott.*)
The cast of a single tube preserved in a coarse sandstone.

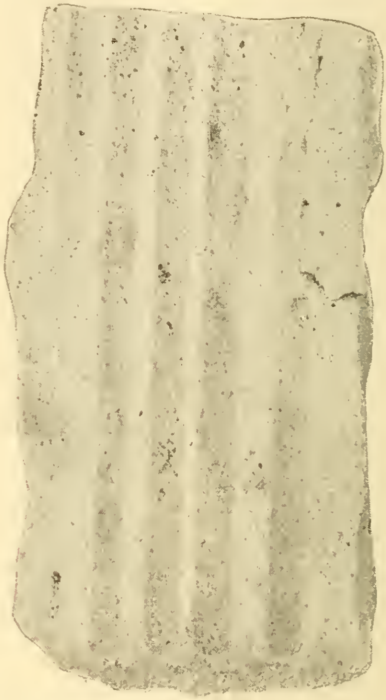


FIGURE 4—*Scolithus linearis, Haldemann.* (*After Walcott.*)
Tubes filled with sand of a darker color than the matrix.

any difference between them. He referred the form, without any question, to the vegetable kingdom. His description, which is meager, is as follows:

"Plant composed of smooth round stems, which penetrate the strata vertically. This species is smaller than the one in the Potsdam sandstone, though resembling it in its general characters."

Our figure 5 is copied from that given by Professor Hall. There is scarcely any feature except its geological position to distinguish it from *S. linearis*.

In the same year (1852) we have the first reference of *Scolithus linearis* to the animal instead of the vegetable kingdom. Logan, in a paper on foot-prints occur-

*10th Ann. Rept. U. S. Geol. Survey, 1890, pl. 63.

†Zeitschr. der Deutsche geol. Gesell., Bd. 3, 1851.

‡This paper is noticed by T. R. J[ones] in the Quart. Jour. Geol. Soc. London, vol. viii, part 2, 1852, pp. 18–23.

§Paleontology of N. Y., vol. ii, 1852, p. 6, pl. 2 [misprinted iii in text], fig. 3.

ring in the Potsdam sandstone of Canada,* referred to the species as marking the sandstone abundantly over considerable spaces, saying that it consists, "where the rock is weathered, of straight vertical cylindrical holes, of about an eighth of an inch in diameter, descending several inches, and where the rock is unweathered of corresponding solid cylinders, composed, apparently, of grains of sand cemented by a slightly calcareous matrix, more or less tinged with peroxide of iron. Mr. Hall and other American geologists include them among the fucoids of the rock, but they appear to me more like worm-holes. In one or two instances I have perceived that the tubes are interrupted in their upward course by a thin layer of sand, a portion of which descends into them and stops them up; and from this it would appear that the cylinders were hollow when the superincumbent sand was spread over them. Whatever may be the origin of the tubes, they strongly mark many beds in the upper portion of the sandstone throughout the Canadian portions of its distribution." This opinion has been accepted by most authors who have written upon the genus, although some still adhere to the idea that the fossils are of vegetable origin.

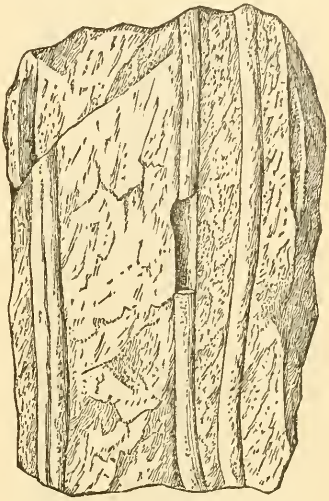


FIGURE 5—*Scolithus clintonensis* (*n. sp.*)= *Fucoides verticalis*, *Hall.* (*After Hall.*)

In 1857 Mr. J. W. Salter noted † finding in the Stiper stones of Shropshire, England, vertical tubes similar to *Scolithus linearis*. He proposed to use the term *Scolithus* or *Scolites* for single tubes or burrows, either vertical or horizontal, but the suggestion does not seem to have been accepted.

In 1858 was published the Geology of Pennsylvania, by Henry D. Rogers. In the course of this report ‡ *Scolithus linearis* is alluded to in one place as a plant, and in another as an annelid burrow. In discussing facts relative to the deposition of the primal white sandstone he says it must have been deposited in quiet waters, because of the "universally perpendicular position of its long slender delicate stem-like fossil, the *Scolithus linearis*, which seems to have been enclosed by the settling sand with as little horizontal bending motion of the stalks from any current as when a field of standing corn is enclosed and bedded up in gently-falling snow."

Again, when referring to the fossils of the Primal strata, he says the species was alluded to in the reports of the Pennsylvania and Virginia surveys under the name of *Tubulites*.‖ He describes it as usually smooth, but sometimes waved or grooved transversely to the axis; always perpendicular, "suggesting the idea of perforations by some marine worm. One end of the fossil always terminates at the upper surface of the bed of sandstone enclosing it, and usually in a rudely flattened knob or head, giving to the whole a likeness to a large, long pin. This knob is probably a cast formed in a wide conical funnel-shaped mouth of a cylindrical perforation." This form is abundant in the Blue ridge of Virginia and at Chickies on the Susquehanna in Pennsylvania. Similar forms occur in higher formations. The figure

*Quart. Jour. Geol. Soc. London, vol. viii, 1852, pp. 199–213.

†Quart. Jour. Geol. Soc. London, vol. xiii, 1857, p. 204.

‡Volume 2, pp. 780, 815–816.

‖ I have been unable to find any use of this name in the reports mentioned.

given by Rogers (figure 6) differs somewhat in the annulated appearance from those ordinarily given, but it can scarcely be anything else than *Scolithus linearis.* It bears a striking resemblance to *Planolites annularius*, Walcott, as figured in a paper on the *Olenellus* fauna.* That figure is here reproduced (figure 7). The species occurs in rocks of lower Cambrian age in Washington county, New York.

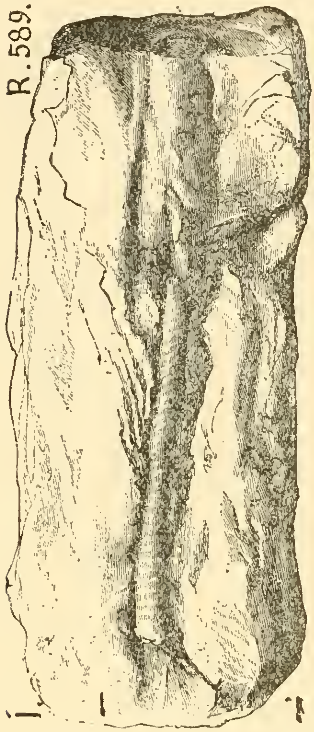


FIGURE 6—*Scolithus linearis, Haldemann.* (*After Lesley.*§)

In 1859 Murchison noted the occurrence of annelid borings in the Stiper stones of England,† referring them to *Scolithus linearis* of the Potsdam sandstone of North America. The Stiper stones are now considered to be of Lower Silurian age.

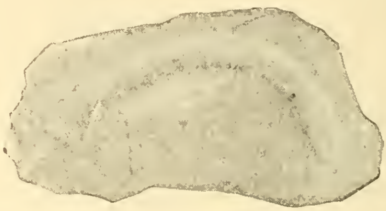


FIGURE 7—*Planolites annularius, Walcott.* (*After Walcott.*)

In 1861 Dr. J. S. Newberry in describing a section at Diamond creek, Arizona,‡ referred to the presence, in shales lying above and below a sandstone, of "great numbers of cylindrical bodies which resemble the casts of worm-holes." These are doubtless *Scolithus* burrows. The rocks overlying the beds with the worm-like bodies are referred to the Potsdam upon lithological characters and "their great relative antiquity." This series is now known as the Tonto group, and is placed in the upper Cambrian.

In 1861 Professor C. H. Hitchcock, in describing the Georgia group of Vermont,‖ referred to *Scolithus* as follows: "The *Scolithus linearis* (Hall) is regarded by some as a plant, by others as a relic of an articulate animal. It generally presents the appearance of numerous linear stems, sometimes three feet long. The stems are generally numerous, and much resemble a series of small pins driven into the rock. Some authors have stated that the axis of this fossil is invariably at right angles with the position of the strata. If so, it may be of great service where it occurs in settling the position of the strata. It certainly would be in both of its localities in Vermont." "Many have considered this fossil as characteristic of the Potsdam sandstone. If this be so, then the age of the quartz rock is certainly known. It certainly has never been described from any other rock; but we do not feel author-

* Tenth Ann. Rept. U. S. Geol. Sur., pl. 60, fig. 5.

† Quart. Jour. Geol. Soc. London, vol. 15, 1859, p. 368.

‡ Rept. on Colorado River of the West, explored under Ives in 1857-'58, part III, 1861, p. 56.

§ Dictionary of Fossils of Pa., vol. 3, 1890, p. 944.

‖ Geology of Vermont, vol. 1, 1861, pp. 356, 357.

ized to accept the positiveness of its evidence, because (1) of its anomalous character; (2) because it is found in a metamorphic rock, and may, therefore, have been altered from some other species of organism, considerably different from the original of the *Scolithus.* For instance, upon the supposition that the quartz rock is middle Silurian, we should imagine the *Fucoides verticalis* of the Oneida conglomerate would change into a form not distinguishable from the *Scolithus linearis.*" This "quartz rock" is now regarded by Walcott as of lower Cambrian age. The figure given by Hitchcock is not distinguishable from *Scolithus verticalis,* Hall (*S. clintonensis* of this paper).

In the same year Mr. E. Billings* referred to *S. linearis* as occurring in the sandstone at l'Anse au Loup, strait of Belle Isle, differing from the common form of the Potsdam of Canada, but being identical with that of the upper Primal of Pennsylvania, and with that of the Potsdam of Tennessee (Number III of Safford). Billings then regarded the form as a plant. The rock at l'Anse au Loup is now considered to be of lower Cambrian age.

In the same volume† appears a description of a new species, under the name of *Scolithus canadensis.* It consists of cylindrical or irregularly prismatic stems (or rather the cavities in the rock once occupied by such stems) "from 1 to 2 lines in diameter and from 1 to 6 inches in length, and either straight or more or less curved. In some specimens several of the stems are in contact with each other, and when this is the case and the stems have an angular shape they very much resemble the coral *Tetradium.* The larger stems are more often straight than the smaller. The true *Scolithus linearis* is generally larger and the stems straight and parallel with each other. It occurs in the upper Potsdam of Canada and on the eastern side of Snake mountain, Vermont."

The species (figure 8) was illustrated in 1863 by Logan,‡ who described the holes as being from $\frac{1}{20}$ to $\frac{1}{4}$ of an inch in diameter. They sometimes penetrate the rock vertically several inches, but in general they are more or less curved and distorted. He says:

> "The casts of the interior of these cavities in freshly broken or unweathered masses of the rock usually appear as solid cylindrical or angular rods, composed apparently of grains of sand cemented by a slightly calcareous matter more or less tinged with peroxide of iron. The origin of these holes is not quite certain; some suppose them to be the remains of fucoids, others of corals, while many are of the opinion that they were the habitations of small burrowing marine or shore-frequenting animals."

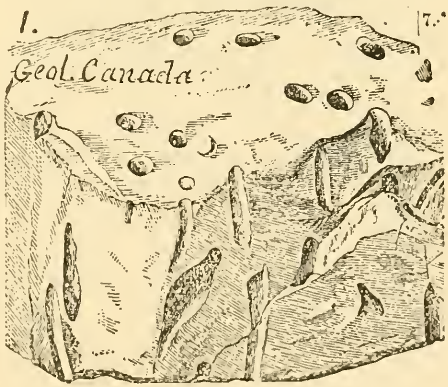


FIGURE 8—*Scolithus canadensis.* (*After Lesley.*§)

He also says that the original specimens upon which the species was founded differ from those above described "in being straight and more decidedly cylindrical, and are therefore probably a distinct species." This remark is at variance with the original description of Mr. Billings, as quoted above.

*Paleozoic Fossils, 1861–'65, p. 2.

†P. 96; first published in 1862.

‡Geology of Canada, from the commencement [of the survey] to 1863. 1863, p. 101.

§*Op. cit.*, p. 943.

In 1869 Billings read a paper before the Montreal Natural History Society on *Scolithus* and allied fossils. This does not appear to have ever been published, but from a notice of it given in *Nature** we learn the author stated that sometimes the specimens can be separated from the rock; that all varieties are marked by undulations; and finally, that specimens from the Potsdam of Canada found by the geological survey "proved that they were not the casts of worm burrows, but sponges." Siliceous spicules, generally elongate-pyriform, are found associated. This is the only reference found in which the sponge nature of *Scolithus* is advanced.

In 1877 Professor J. D. Dana, in giving an account of the researches of Reverend Augustus Wing into the geology of Vermont, mentions a species of *Scolithus* under the name of *S. minutus*.† It is not accompanied by any description, and I cannot find that it has ever been described. The name was probably applied by Wing to some small worm burrows found during his researches. Professor Ezra Brainerd has kindly sent me a specimen of this form, and it may be described as follows:

Scolithus minutus, Wing. Cavities penetrating the rock in various directions, generally vertically and opening at right angles or obliquely to the surface. Holes varying from $\frac{1}{32}$ to $\frac{1}{8}$ of an inch in diameter; never branching, but sometimes slightly curved (figures 9 and 10).

It occurs in the Calciferous formation of Vermont, and its geological position is perhaps the only reason for considering it distinct from *S. canadensis*.

Figure 9—*Scolithus minutus*, *Wing*. (*Original*.) Surface, showing openings of burrows.

In 1878 Messieurs Miller and Dyer described a species of *Scolithus* under the name of *S. tuberosus*.‡ It is quite different from any other species of *Scolithus* described. The authors say of it:

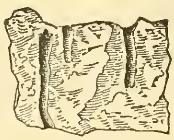


Figure 10.—*Scolithus minutus*, *Wing*. (*Original*) Showing burrows in rock.

"The holes (sometimes called stems) are curved or winding, and pass through the rock in an irregular course, sometimes uniting or branching, but never passing vertically through the strata as in *S. linearis*, from the Potsdam group. Upon the upper surface of the rock the tubes are prolonged into a crateriform elevation, which is rarely at right angles to the surface of the rock. These resemble, on a smaller plan, the mud elevations, thrown up around the holes, made by the common crawfish on our fresh-water streams.

"The holes are not tapering, but maintain a somewhat uniform diameter. Diameter generally about 2 lines; sometimes nearly 3.

"This species resembles the burrow of some animal more clearly than any hitherto described, and bears no resemblance to any of our fucoids. It has been frequently, but very erroneously, referred to *S. linearis*."

* Volume 1, 1869, pp. 248, 249.

† Am. Jour. Sci., 3d ser., vol. xiii, 1877, p. 342.

‡ Privately printed pamphlet, entitled Contributions to Paleontology, No. 2. 1878, p. 5.

Figure 11 is reproduced from the figure given by the authors. The description does not agree with the generic description of *Scolithus*, and it is evidently not congeneric with *S. linearis*. It should be referred to a separate, probably a new, genus.

FIGURE 11—*Scolithus* (?) *tuberosus, Miller and Dyer.* (*After Miller and Dyer.*)

In 1878 Dr. T. S. Hunt, in a special report on the trap dikes and Azoic rocks of Pennsylvania,* gave a short history of *Scolithus*. He referred to the descriptions of Haldemann, Hall and Rogers, and quoted the description of Billings and his remarks relative to *S. canadensis*. He said that examples of *Scolithus* from the Potsdam of Wisconsin appear to be identical with *S. canadensis*, and, although probably distinct, are more like *S. verticalis* from the Medina than *S. linearis* from the Primal of Pennsylvania. He says further: "It would appear that even in the typical Potsdam sandstone there have been confounded under this name the marks of distinct and unlike objects." † Some beds at Port Henry, New York, contain impressions which have been designated *Scolithus*. These are described as cylindrical cavities with a central tube. In weathered specimens, where this central tube has disappeared, the cavities resemble the burrows of a worm. "But," he says, "in either condition they are evidently very distinct, both from the prismatic shapes noticed by Billings under the name of *Scolithus canadensis* and the transversely grooved cylindrical rods of the Primal white sandstone." ‡

In 1880 Professor R. P. Whitfield described a form from the Potsdam of Wisconsin which he called *Scolithus* (?) *woodi.* § It consists of vertical and usually cylindrical perforations, about a line or a little more in diameter, and from 1 to several inches in length. They are straight or variously bent, but never bifurcating or branching. The walls are usually smooth, but occasionally one is corrugated (figure 12). In his comparisons with other forms it was said that while *S. linearis* is from $\frac{1}{8}$ to $\frac{1}{2}$ inch thick, and often several feet in length, the western forms are seldom even $\frac{1}{8}$, and often $\frac{1}{16}$ of an inch in diameter. Though normally vertical, they are frequently deflected at various angles or even run obliquely. On some blocks many little elevations appear about the mouths of the burrows, and the surface is covered with trails of annelids (figure 13).

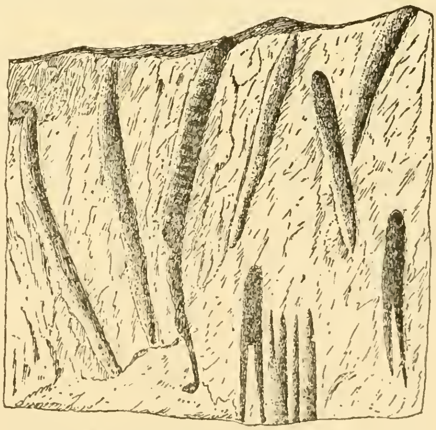


FIGURE 12—*Scolithus woodi, Whitfield* (*sp.*). (*After Whitfield.* ‖) Sectional view.

* Second Geol. Sur. Penn., E, 1878, pp. 135–139.

† *Ibid.*, p. 138.

‡ *Ibid.*, p. 139.

§ Ann. Rept. Wisc. Geol. Sur. for 1877, 1880, p. 45.

‖ Geology of Wisconsin, vol. iv, 1882, pl. 2, figs. 1, 2.

In a later publication* Professor Whitfield referred this form to the genus *Arenicolites*, considering that while there might be some doubt as to the animal origin of *S. linearis* of New York, there was no question about the animal origin of the Wisconsin form.

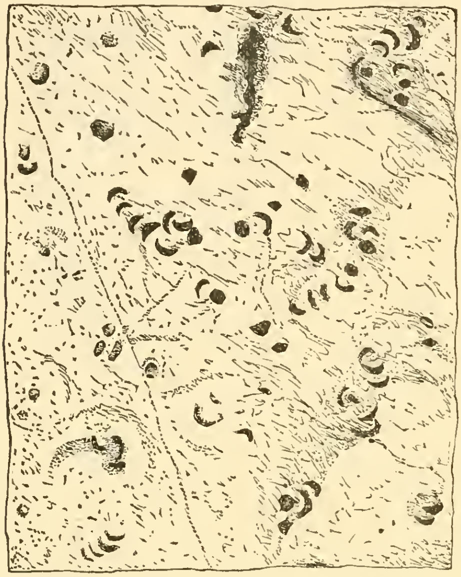


FIGURE 13—*Scolithus woodi* (*sp.*). (*After Whitfield.*) View of surface of slab.

In 1881 Nathorst † referred to the occurrence of *Scolithus* in northern Germany, and he notes that Dames expressed some doubt, in which he himself shared, as to the organic origin of the species. This doubt arose from the fact that the tubes were always parallel and never transverse. Some specimens, however, he considered were undoubtedly worm tubes.

In 1881 Mr. U. P. James ‡ mentioned a species referred to by him as perhaps *Scolithus linearis* occurring in the Cincinnati group of Ohio. It is found on the under side of slabs of limestone, and is described as follows:

"The fossils are shown in strong, raised lines, from 1–24 to over ½ inch or more wide, generally straight and parallel to each other, but not always so."

Should the species prove to be distinct from *S. linearis* it was proposed to call it *S. dispar*. This form is not a *Scolithus* in any sense of the word, but is probably a species of *Eophyton*. The lines were produced by the passage of some organism over the surface of soft mud (figure 14).

On the same page of the above publication a second species is described under the name of *Scolithus delicatulus* (figure 15):

"It consists of small, cylindrical stems, from half a line to one line in diameter, passing vertically through the strata, irregularly arranged from ⅛ to ¼ of an inch apart, more or less. The appearance is as if soft mud, forming the strata, had been deposited gently around the plants without disturbing their erect position. * * * On the under side the plants are broken off even with the surface, or leaving small, shallow pits; on the upper surface they are elevated from half a line to over one line."§

As we see, this form was considered a plant, but there can be no question about its being a worm burrow.

In 1883 Professor T. C. Chamberlin ‖ figured *Scolithus* (?) *woodi*, Whitfield, as *Arenicolites woodi*, saying he preferred this name, as the annelidan character of the fossil had been determined.

---

* *Ibid*, p. 177.

† On traces of some invertebrate animals and their paleontological significance (in Swedish and French): Stockholm, 1881.

‡ The Paleontologist, No. 5, June 10, 1881, p. 33.

§ *Ibid.*, pp. 33, 34.

‖ Geology of Wisconsin, vol. 1, 1883, p. 128.

In 1884 Professor N. H. Winchell, in a description of the geology of Rice county, Minnesota,* noted in the St. Peter sandstone great numbers of circular holes. They are always perpendicular, and can be traced 2½ feet by furrows on the surface of the rock. It was at first ascribed to the burrowing of Cretaceous mollusks, "but," Professor Winchell says, "it is more likely to be due to some marine vegetable, or to worm-burrowing of Cambrian age." "It would be the same as if a multitude of horse-tail rushes or others were growing in the bottom of the sea when the sand was accumulating and became gradually buried under the sand, and then were imprisoned and fossilized, their presence only being evinced now by the cementation of the sand grains about their exterior, or by a looseness of the same in their interior." The spots were only seen on upper surfaces of the rocks, and were from ⅛ to ¼ of an inch in diameter.

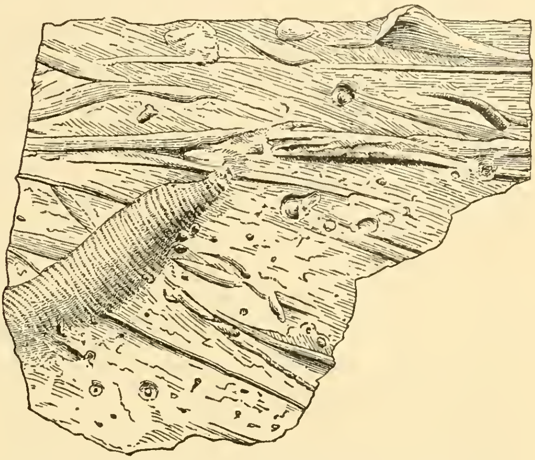


FIGURE 14—*Eophyton* (*Scolithus*) *dispar*, *U. P. James* (*sp.*). (*Original.*)

This is also probably a species of *Scolithus*, possessing some of the characters of *linearis*, some of *woodi*, some of *delicatulus*. Professor Winchell gave no name to the form, but I propose to call it *Scolithus minnesotensis*. It is probably this same form that occurs at Beloit and other places in Wisconsin.

In 1887 Ami referred † to the existence of *Scolithus* in Chazy strata, stating that although *Scolithus* had been considered to indicate the rocks containing it were Potsdam, its occurrence at other horizons shows the beds may be of a later age.

In the same year Messieurs Ami and Sowter concluded,‡ as a result of the examination of an extensive series of specimens from the Potsdam of the province of Quebec, that *S. linearis* and *S. canadensis* were identical. The main difference between the two, they concluded, was in the preservation, the former occurring as casts of the burrows or holes, while the latter were the burrows themselves.

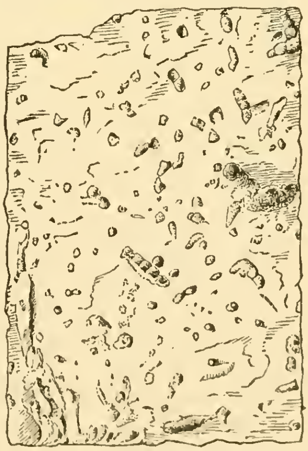


FIGURE 15—*Scolithus delicatulus*, *U. P. James.* (*Original.*)

In 1890 Atreus Wanner referred § to *Scolithus* occurring in great abundance in the Hellam or

*Geology of Minnesota; Final Report, vol. 1, 1884, pp. 656, 657.

†Canadian Rec. Sci., vol. ii, 1887, pp. 304–306.

‡Ottawa Naturalist, vol. i, 1887, pp. 96, 97.

§American Geologist, vol. v, 1890, pp. 35–38.

Chickies quartzite of York county, Pennsylvania. He gave illustrations of the tubes, flattened by pressure, and showed also an exposure of the quartzite with great numbers of the tubes, often only ¾ of an inch apart. No explanation is given of their origin. This locality is the one from which the original specimens of Haldemann came, and the form is doubtles the true *Scolithus linearis*.

In the same year Brainerd and Seely, in a description of the Calciferous of the Champlain valley,* mention the occurrence of *Scolithus minutus*, Wing. This is considered a burrow, and the authors say:

"The fucoids, so far as we have seen, are not characteristic of any one division, though they appear abundantly in various horizons of D. Further, *Scolithus* cannot be regarded as indicating a Potsdam horizon, as the most abundant display we have ever seen is to be found at the bottom of Division C, 600 or 700 feet above the Potsdam sandstone."

In 1890 Professor J. P. Lesley referred † to and figured *Scolithus canadensis* and *S. linearis*. Both were considered by him to represent worm burrows in rocks of Potsdam age. He also says: "But the old idea that *Scolithus* characterizes and determines the Potsdam sandstone must be abandoned" (page 943). He then refers to the work of Brainerd and Seely, quoting their remarks on *Scolithus* burrows in the Calciferous, and he also mentions numerous localities in Pennsylvania where *S. linearis* occurs, referring the rocks to the Potsdam. He also says that similar worm burrow casts occur in the outcrops of Medina sandstone.

In 1890 C. D. Walcott, in an account of the fauna of the lower Cambrian or Olenellus zone,‡ states that *Scolithus* appears to range through the Cambrian. Burrows in the Potsdam or upper Cambrian are similar to those in the lower Cambrian; and though it is not considered probable that the same species of animal made the burrows in the two epochs, there are no means of separating them. All the Cambrian forms are referred to *Scolithus linearis*.

In Bulletin No. 81 of the U. S. Geological Survey § (just issued) Mr. Walcott gives numerous references to *Scolithus linearis* and its occurrence in Cambrian strata. From these it appears that numerous correlations of rocks from widely separated localities have been made upon the evidence of this fossil.

During the field season of 1889 I found at various points in Wisconsin and Minnesota specimens of *Scolithus*. At Madison, Wisconsin, for example, the tubes occur in abundance, penetrating the rock in all directions. Near Ableman I found one specimen having the shape of the letter U, both ends opening at the surface; otherwise it was exactly like the ordinary specimens of *Scolithus linearis*.

Near Merrillan, Wisconsin, on an isolated mound 1½ miles southeast of the railroad station, an outcrop of sandstone occurs, part of which has a columnar appearance. When weathered, the columns stand out in relief and the top of the rock has the appearance of a honeycomb with the cells sealed up. The same appearance is presented by a sandstone 3 miles to the northward. These appearances are probably due to *Scolithus* borings.

From the review here given it is seen that, originally described as a marine fossil plant by Haldemann, the annelidan character of *Scolithus* was first pointed out by

* Bull. Geol. Soc. Am., vol. 1, 1890, pp. 501–511.

† Dictionary of fossils of Pennsylvania; Second Geol. Sur. Penn., P4, 1890, pp. 943–945.

‡ Tenth Ann. Rept., U. S. Geol. Sur., 1890, pp. 603, 604.

§ Correlation papers; Cambrian: 1891, p. 447.

Logan in 1852. Since then some authors have considered it as possibly a fossil plant, but the great majority recognize it as a worm burrow. Billings, in 1869, was the only one to refer it to the sponges.

There have been described of the genus from North America the following species:

Scolithus (*Fucoides*) *shepardi*, Hitchcock, 1833 (Triassic).

S. linearis, Haldemann, 1840 (lower Cambrian).

S. (*Fucoides*) *verticalis*, Hall, 1843 (Portage).

S. clintonensis (n. sp.), proposed for *S. verticalis*, Hall, 1852, preöccupied (Clinton and Medina).

S. canadensis, Billings, 1862 (Potsdam).

S. minutus, Wing, 1877 (Calciferous).

S. tuberosus, Miller & Dyer, 1878 (Cincinnati).

S. (*Arenicolites*) *woodi*, Whitfield, 1880 (Potsdam or St. Croix).

S. delicatulus, U. P. James, 1881 (Cincinnati).

S. dispar, U. P. James (= *Eophyton dispar*), 1881 (Cincinnati).

S. minnesotensis (n. sp.,), Winchell, 1884, described but not named (St. Petero).

The geological range of the genus appears from this list to be from the lower Cambrain to the Triassic. *S. shepardi* from the Triassic does not differ in any essential respect from *S. linearis* from the Cambrian. It is impossible to separate *S. verticalis* of the Portage from *S. clintonensis* of the Clinton and Medina, or either of these from *S. linearis*. As we have already shown, *S. canadensis* and *S. linearis* may be considered identical; while *S. minutus* from the Calciferous and *S. woodi* from the upper Cambrian of the Mississippi valley may be said to be separable by no definable characters. *S. delicatulus* from the Cincinnati differs from *S. minutus* only in having the cavities of the tubes filled instead of being hollow. Finally, *S. minnesotensis* from the St. Peter is the same, so far as characters go, as *S. linearis* from the lower Cambrian.

It cannot be considered as at all probable that the annelid living in the lower Cambrian and making the perforations we know as *S. linearis* persisted in the same form through all later geological periods into Triassic time. Mr. Walcott does not think it probable that the same species ranged even through Cambrian time, to say nothing of a much greater time-range. Yet he places forms from the lower and from the upper Cambrian under the same specific name. On the same principle we should unite all the species, in whatever geological horizon they may occur, under one name, for there are no characters to distinguish one from another. But this does not seem advisable, and under the circumstances I would propose that the geological position shall decide the name to be used. Thus, *S. linearis* might be applied to forms from the lower Cambrian rocks of the eastern United States; *S. canadensis* to those occurring in upper Cambrian strata of the eastern United States, and *S. woodi* to those from strata of similar age in the upper Mississippi valley; *S. minutus* might be the name for the form in Calciferous strata; *S. minnesotensis* might be applied to the forms from the St. Peter, and *S. delicatulus* to those in Cincinnati rocks; *S. clintonensis* might be applied to those from Clinton and Medina strata, *S. verticalis* to those from the Portage, and *S. shepardi* to those from the Triassic. It is probable, also, that a name should be given to forms collected from other horizons, say *S. arizonicus* to the form from the Grand cañon in Arizona.

Several objections may be urged against such an arrangement. One of these is that it robs the genus of all value as indicating the age of the rocks in which it

occurs. This is true. It deprives *Scolithus*, too, of any value as a means of correlating rocks of two different sections, one with another. This is also true, and so it should be. No valid argument can be brought forward to justify placing the rocks of two widely separated areas in the same terrane upon the evidence of such a form as *Scolithus*—a form of indefinite character, of indefinable features, of perplexing variability, and of wide time range. The use of forms of this sort as a means of correlation is even worse than the use of lithological character. Time does not permit mentioning the erroneous correlations resulting from the use of *Scolithus*, but they are numerous enough.

A second objection urged will probably be the multiplication of names resulting. Some will, perhaps, prefer to let *Scolithus linearis* do duty for all the forms if they can be shown to be indistinguishable; but this objection does not seem to me to be a valid one. Dr. C. A. White, in a paper read before the American Association for the Advancement of Science last year and published in volume 39 of the proceedings, in speaking of applying new names to fossils occurring in two different formations, says that "if a given formation is found to bear a fossil fauna the component members of which, with such exceptions as have been referred to (*i. e.*, forms considered identical in two formations) are all unlike those of any other known fauna, I think it admissible to treat the whole fauna as new and to give a new name to each species" (p. 242). My own studies of *Scolithus* led me to adopt this method previous to reading Dr. White's paper, and I have therefore proposed, as seen above, to characterize the species of *Scolithus* upon the formation, and not, as has been done at times, the formation on the occurrence of the species.

The paper by Mr. James was discussed by N. S. Shaler and E. W. Claypole. Professor Shaler advised neglecting altogether the specific names for *Scolithus*, since it is at best only a hole in the rock. He also regarded Billings' observations on sponge spicules as valueless, because anything so widely distributed as these spicules would be readily swept into small crevices or openings, such as the *Scolithus* perforations. Professor Claypole remarked that *Scolithus* persists to the present time.

The following paper was then read:

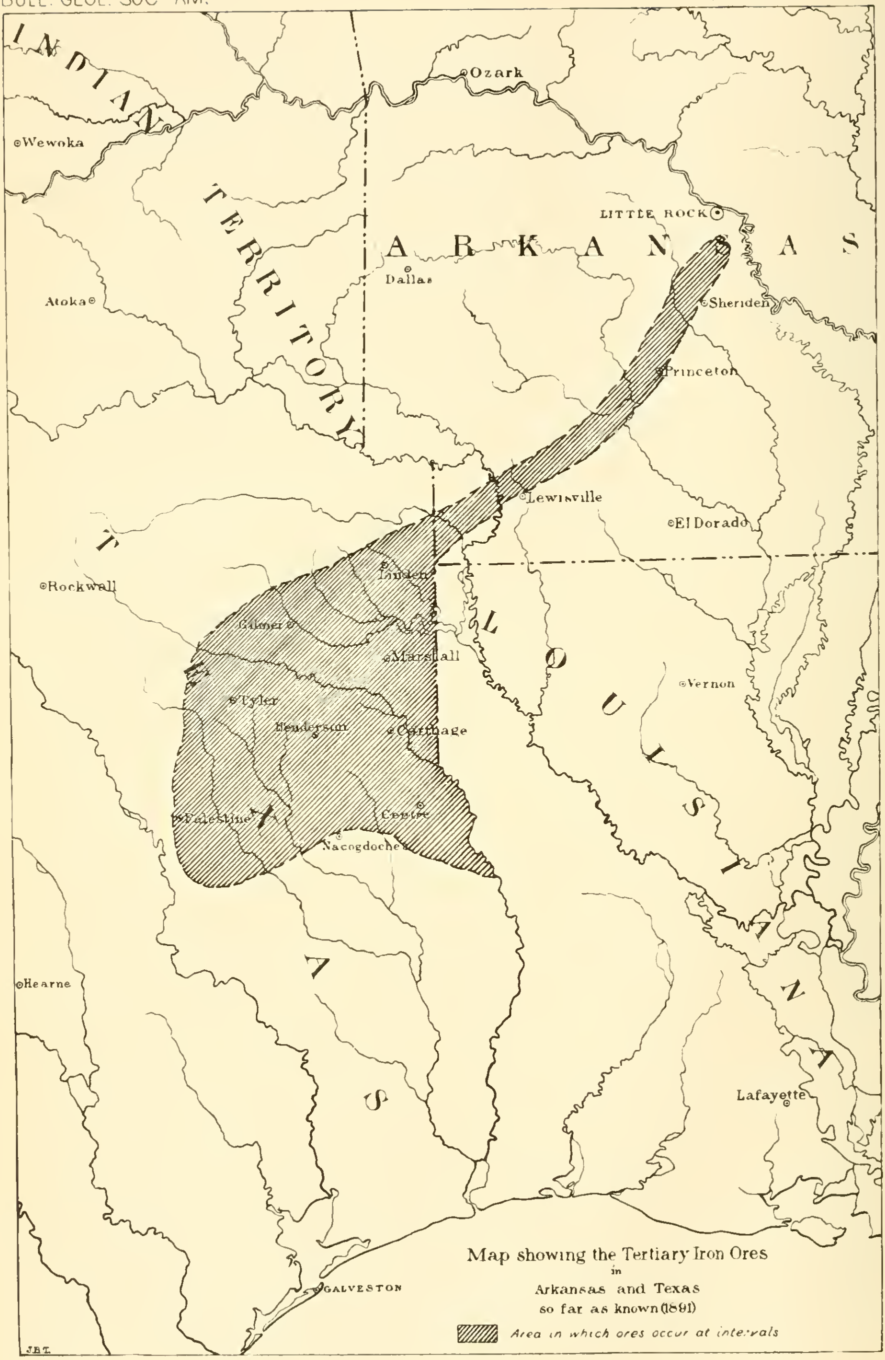
THE TERTIARY IRON ORES OF ARKANSAS AND TEXAS.

BY R. A. F. PENROSE, JR.

Contents.

Distribution of the Ores.

The Tertiary iron ores of Arkansas and Texas as now found are hydrous sesquioxides of iron, generally occurring as limonites or allied forms. They occupy a belt of country running northeastward and southwestward through the southern part



Map showing the Tertiary Iron Ores in Arkansas and Texas so far as known (1891)

of Arkansas and the eastern part of Texas. On the northeast they commence a few miles south of Little Rock, cross Saline river south of Benton and Ouachita river between Arkadelphia and Camden, and reach Red river north of Lewisville. Southwest of the Red river bottom in Texas they again appear in the border counties of Bowie, Cass, Marion and Harrison, and around the upper waters of Sabine river. Thence the belt bears southwestward across Angelina, Neches and Trinity rivers, finally thinning out before the Brazos is reached. The length of this belt is over 300 miles; the width varies from 1 to 50 miles. The ore is not found continuously throughout this area but occurs intermittently, the ore-bearing areas being often separated by much greater barren areas. The distribution is shown approximately in plate 1.

Associated with the ores there are often found beds of sandstone, representing local areas of sand indurated by the percolation of ferruginous solutions and often locally mistaken for iron ore. Such deposits pass by abrupt gradations, both vertically and laterally, into loose sands.

With the exception of the iron ores and the sandstones, all the strata of the region are of a loose, incoherent nature, and therefore these factors have been largely instrumental in controlling the topography of the country. The strata are all either horizontal or dip by almost insensible gradations toward the Gulf of Mexico. They have suffered considerably from erosion, and the usual topography, where the harder materials are absent, is almost flat or gently undulating in sandy hills. Where the ore and sandstone are present, the region is much more broken and is composed of abrupt hills and ridges, flat on top and sloping off rapidly toward the creeks and river bottoms. Though these hills are rarely more than from 100 to 300 feet above the surrounding drainage, they are in marked contrast with the usual Tertiary topography, and are locally known as "mountains." Their form has been regulated by the harder strata, namely, iron ore and sandstone, which, resisting erosion better than the associated clays and sands, have protected the beds immediately under them, while those above them have generally been largely and sometimes altogether removed. As a result of this erosion, the iron ores as well as the sandstones usually cap the hills, and the heaps of broken rock give a rugged character strongly contrasted with the usual sandy or clayey Tertiary surface of the Gulf states. Occasionally a covering of sand or sandy clay still overlies the ore beds, and in such cases the ore is seen only where it crops out on the slopes, forming a rocky rim around the hills or along the slopes of the ridges. Besides the ore and sandstone on or near the tops of the hills, similar beds are sometimes found below, cropping out on the lower slopes.

As the ore is of only local extent, so the flat-topped hills are only local, while elsewhere the less resistant strata have been eroded down to the surrounding level.

Geologic Relations of the Ores.

The geologic position of the ores is in the Eocene series of the Tertiary, and probably in or below the Claiborne horizon of that series. Two principal divisions in the Eocene contain noticeable quantities of ore, though more or less iron is characteristic of the whole series. The lower one is in the great section of sands and sandy clays which form the central part of the Eocene; the upper one is at the top of the Claiborne glauconite that overlies these beds. The lower deposits are extensively developed in both Arkansas and Texas, and comprise by far the

larger part of the iron-ore belt. They are not confined to one individual stratum, but occur in various positions in the beds of which they form a small yet characteristic part. The upper deposits are extensively developed in Texas, in the area south of those just mentioned, especially in Cherokee, Smith, Rusk, Nacogdoches and other counties. The correlatives of the latter deposits have not yet been identified in Arkansas, and it is somewhat doubtful whether they exist, though certain iron ores in glauconite have been found in the valley of the Ouachita. The eastern extension of the Texas ore-bearing glauconite, however, is probably to be looked for in northern or western-central Louisiana, an area in which the iron ores have not yet been thoroughly investigated.

Nature of the Ores.

Though the ores occupying the lower and upper positions just mentioned are much the same in chemical composition, being in both cases hydrous sesquioxides of iron, they differ considerably in their physical character, and may be classified under the two headings of *nodular ores* and *laminated ores*. The former represents the lower horizon; the latter represent the upper or glauconitiferous horizon.

Nodular Ores.—The nodular ore is characterized by the nodular character of the component parts of the ore beds, though it also occurs in mammillar, stalactitic or botryoidal masses. The nodules are often, and in some places generally, hollow, representing geodes, and vary from a fraction of an inch to several feet in diameter. They are frequently cemented together by ore, or by a ferruginous sandstone, forming a more or less continuous bed, while at other times they occur loose in the enclosing sands and clays. They generally are partly filled by a yellow, brown, or

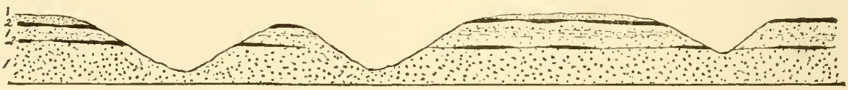


Figure 16—*Ideal Section showing the Mode of Occurrence of the nodular Ores.*
1 = Sands and sandy clays; 2 = Ore beds.

red clay, and sometimes by a ferruginous ochre. They vary from yellow or brown to almost black in color, and the geodes are usually lined on the inside by a brilliant black gloss. Sometimes the outer part of a nodule is an amorphous mass, while the inside exhibits the fibrous character of certain hydrous sesquioxides of iron. The more solid nodules show a concentric structure, the individual layers being often separated by narrow spaces which generally contain more or less earthy matter. Frequently this variety of ore occurs in beds separated by horizontal layers of sand or sandy clay, the individual beds varying from a fraction of an inch to many feet in thickness. The accompanying ideal section (figure 16) represents a characteristic mode of occurrence of the nodular ores.

Laminated Ores.—The laminated ore is of a rich chestnut-brown color, often resinous in luster. It usually has a more or less laminated structure, which, though it sometimes blends into a massive variety, is generally composed of thin layers varying from a sixteenth to a quarter of an inch in thickness. The laminæ are separated by narrow spaces, often containing a gray clay, and are frequently coated with a black gloss. The ore occurs in horizontal beds from one to three feet in thickness, sometimes continuous over many acres, elsewhere in isolated patches. It is composed of masses which are flat or slightly concave on top, and bulging or

mammillary below. It directly overlies a bed of glauconite, which varies from thirty to forty feet in thickness and which is underlain in turn by a series of sands and clays. It sometimes crops out on the immediate summits of flat-topped hills, but is more often covered by from one to twenty or more feet of sandy clay, which represents the remains of the overlying strata, as already described. The glauconite bed contains considerable quantities of iron pyrites and numerous Claiborne fossils.*

Sometimes thin seams of iron ore occur in the glauconite below the main ore bed, but they are usually small. Between the main ore bed and the overlying sandy clay there is a layer of dark-brown hard sandstone varying from one to six inches

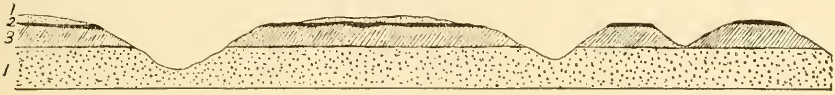


FIGURE 17—*Ideal Section showing the Mode of Occurrence of the laminated Ores.*
1 = Sands and sandy clays; 2 = Ore bed; 3 = Glauconite (greensand).

in thickness and averaging probably one and a half inches. The ore crops out on the brinks of the hills, forming a protruding rim or crown and often covering the slopes with large masses that have broken off from the main bed. The accompanying ideal section (figure 17) represents a characteristic mode of occurrence of the laminated ores.

ORIGIN OF THE ORES.

In inquiring into the origin of the iron ores of the Gulf Tertiary it is necessary to consider the conditions surrounding the deposition of the great series of alternating sands and clays which comprise the mass of the strata. That they are a littoral formation is proved by the character of the organic remains enclosed in them; by the not infrequent occurrence of pebble beds (especially in Arkansas); by the lateral blending of marine and brackish water or lagoon deposits; and by the rolled and rounded character of many of the shell fragments, shaped as if by continued beating on or near a sea beach. Again, the frequent occurrence of extensive beds of lignite at various horizons would indicate conditions of deposition which permitted numerous ready transitions from marine to land or coastal-lagoon environments. Such conditions doubtless gave rise to large areas of swamps and shoals along the coast of the Tertiary embayment, probably not unlike those now seen in places on the coasts of Florida and Louisiana, and around the lower part of Sabine river in Texas. Into these basins the waters from the land drained and probably often remained in a semi-stagnant state for considerable periods, undergoing a considerable evaporation.

The rocks forming the coast of the Tertiary Gulf of Mexico all contained greater or less quantities of iron-bearing materials: The glauconite of the upper Cretaceous of Texas and the Paleozoic and pre-Cambrian rocks to the west of the Cretaceous area were a ready source of iron to the circulating waters; while the Carboniferous and Silurian shales and sandstones of central and southwestern Arkansas supplied an important quantity of iron to the waters tributary to the Gulf. These waters, draining into the coastal lagoons and swamps, were subjected to active oxidizing

*See Angelo Heilprin: The Eocene Mollusca of the State of Texas, Proc. Acad. Nat. Sci. Phila., part III, Oct-Dec., 1890, pp. 393–406.

influences which eventually caused the precipitation of the soluble salts of iron contained in them, and this action may have been greatly facilitated by the considerable evaporation that probably took place.

The form in which the iron was precipitated depended on the local conditions surrounding each area: Where iron in the form of sulphate came in contact with a reducing agent, or where other salts of iron were in the presence of sulphuretted compounds derived from decaying organic matter or from other sources, then the iron was often deposited as sulphide (iron pyrites); otherwise the iron might have been laid down as either oxide or carbonate, or as glauconite. Subsequent segregation doubtless often assisted in the accumulation of the ore in certain areas.

Though the large bodies of iron ore now found in the Tertiary area are in the form of oxides, there is decided evidence that they were originally segregated as carbonate and sulphide. It is very probably, however, that the original deposition may often have been as oxide, and that the forms of sulphide and carbonate were produced during a subsequent segregation into nodules and layers.

The nodular ores already described have doubtless been largely derived from the oxidation of an impure carbonate of iron in the form of the so-called clayironstone. This material is of common occurrence throughout the Tertiary strata, though it is usually seen only in protected places, such as in well-borings, in some creek bluffs, and in other places in which it has not been exposed for a sufficiently long time to undergo oxidation; while, where it has been so exposed, it has been converted to a more or less hydrous sesquioxide. The strongest evidence of this derivation of the nodular ores is that in many places they can be seen in the actual process of transition, and it is not an uncommon occurrence to find masses of the as-yet unoxidized clayironstone forming the kernels of the nodules. Moreover, the masses of ore are often composed of aggregations of angular geodes, the angles of which are so arranged that if they were brought together they would form one solid mass of geodes. In most of the unaltered clayironstone masses there are numerous shrinkage cracks, and it seems probable that the shape of the angular geodes has been regulated by the directions of these cracks, which caused the mass to be more or less divided into separate parts, each part afterward forming a separate geode.

The clay already mentioned as often occurring in the geodes doubtless represents the residual insoluble product left after the oxidation of the clay-ironstone.

This mode of derivation is by no means confined to the Tertiary ores: It is described by many writers in iron ores in various Paleozoic horizons. Dr. T. Sterry Hunt* explains the formation of the geodes by the gradual shrinkage in the transition from carbonate to oxide of iron, causing a diminution of volume equal to 19.5 per cent of the original mass. The transition progresses from without inward, forming layer after layer of oxide, often separated by spaces as a result of contraction, while in other nodules the whole shrinkage is represented by the central cavity alone. Hence sometimes the concentric nodules; at other times the hollow geodes.

The laminated ores, which are especially well developed in Cherokee county, Texas, appear to have been derived largely from iron pyrites, assisted probably in some cases by carbonate of iron and glauconite. As already stated, the laminated ore directly overlies a large glauconite bed in which iron pyrites is of common occurrence. In some few places, when natural conditions have protected the beds from atmospheric influences, it is found that the pyrite is especially abundant at

* Mineral Physiology and Physiography, 1889, p. 262.

the top of the glauconite bed and immediately below the overlying clayey sand. Here it occupies the same position as the laminated ore elsewhere and is frequently associated with sands and clays which often contain lignite. The thin layer of sandstone found overlying the laminated ore frequently contains masses of lignite completely converted to iron ore, and these probably represent the alteration product of the lignite originally associated with the pyrite.

The following section at the McBee school-house, near Alto, Cherokee county, Texas, shows a case of the original condition of the iron pyrites:

1. White sandy clay varying from	10–30 feet.
2. Ferruginous sandy clay becoming indurated at base	1 foot.
3. White sandstone with a cement of profusely disseminated iron pyrites	1–3 inches.
4. White sand with lenticular masses of lignite (1 to 4 inches in thickness) and many disseminated particles of iron pyrites, passing below into a plastic greenish-brown clay	3 feet.
5. Dark-green glauconite at bottom of section	——

This section appears to represent the original condition of the strata before the formation of the laminated ore. That ore usually occurs immediately above the glauconite represented in number 5 of the section, but here the same position, that is, above the glauconite and below the sandy clay, is represented by some four feet of sandy and clayey strata highly charged with iron pyrites. This mineral, by its oxidation, forms sulphuric acid and sulphate of iron, the latter sooner or later becoming still farther oxidized and going into a hydrous sesquioxide of iron. It seems probable that the combined action of the sulphuric acid and sulphate of iron percolating down from the pyritiferous sands into the clay causes an interchange of constituents, and that the clay is to a greater or less extent converted into iron ore. This would account for the considerable percentage of alumina usually found in the ore, and also for its laminated structure, a structure often seen in the unaltered clay. The thin layer of sandstone, which has already been mentioned as capping the laminated ore, is probably due to the induration of the sandy stratum immediately overlying the clay by the peroxide of iron derived from the oxidation of the pyrite.

The shape of the ore bed is strong evidence of the formation of the ore by the process just described: the upper surface of the bed is usually flat, but the base of it is very uneven and shows a series of bulging and receding mammillary forms. These masses are often distinct from each other, but are closely assembled together in a continuous or almost continuous stratum. The upper surfaces of the ore masses are often concave, while the lower surfaces are convex, apparently pointing to derivation by the downward percolation of the ferruginous solutions as already described.

The glauconite itself may in some cases have assisted in the formation of the laminated ore, but its influence has probably been small. Glauconite is doubtless an important source of iron in surface waters, and the ferruginous solutions derived from it may often be precipitated elsewhere and accumulated in considerable beds of ore; but the case in question is one of the formation of brown hematite *in situ*, and in such a process glauconite does not seem, at least in the Tertiary area of Arkansas and Texas, to have been so important a factor as the carbonate and sulphide of iron.

Besides the pyrite at the top of the glauconite bed, the same mineral is often found in greater or less quantity lower down in the formation, and where it has been oxidized it gives rise to masses and layers of hydrous sesquioxide. Carbonate of iron in the form of layers or nodules or as a finely disseminated material is also a common constituent not only of the special glauconitic formation in question, but also of many other Tertiary glauconites of the Gulf basin, and by its oxidation also gives rise to the hydrous sesquioxide. The ferruginous solutions derived from the pyrite or carbonate often percolate through the glauconite bed and deposit thin layers of brown hematite in joint cracks and along lines of bedding, often giving the impression that the ore has been derived from the oxidation of the glauconite. In some cases the glauconite has undoubtedly supplied a part of it, but the fact that the largest quantities of the sesquioxide are found in those parts of the glauconite beds which contain most carbonate or sulphide of iron is strongly suggestive of the greater influence of the last two as sources of the sesquioxide. The long-continued action of sulphuric acid derived from the oxidation of pyrite, and of carbonic acid derived from carbonate of iron, however, have had their effect in decomposing the glauconite, and their influence is shown by the fact that where oxidation has gone on in the pyrite and carbonate the originally green glauconite is converted to a yellow or rusty, more or less indurated mass. Sometimes it is hardened to such an extent as to be used for building stone. A similar alteration of the glauconite takes place even where the sulphide and carbonate are absent, but less rapidly than where they are present. In fact, in the region of the ores associated with glauconite in eastern Texas the whole formation presents a yellow or brown surface exposure, while at depths of from a few inches to twenty feet or more in the interiors of the hills the original green color is preserved.

Conclusions.

From the above discussion the following general conclusions have been reached:

1. That the iron ores of Texas and Arkansas occur mostly in two positions in the Eocene series of the Tertiary.
2. That the ores were originally deposited in the form of oxide, carbonate and sulphide contemporaneously with the associated strata, and that they were subsequently segregated mostly as carbonate and sulphide.
3. That the ores as now found are the products of the oxidation of the carbonate and sulphide, the nodular ores being derived from the carbonate and the laminated ores from the sulphide of iron.

Professor I. C. White was called upon to take the chair, and the following paper was read:

SANDSTONE DIKES IN NORTHWESTERN NEBRASKA.

BY ROBERT HAY.

At the meeting of the American Association for the Advancement of Science at Ann Arbor in 1885, Professor A. R. Crandall read a paper on "The occurrence of trap rock in eastern Kentucky," away from all centers of eruption. In the ensuing discussion, Professor L. E. Hicks, of Nebraska, mentioned a dike near Chadron, in

northwestern Nebraska, which was likewise distant from eruptive centers, but stated that the material was *sandstone*. Last winter, at the meeting of the Geological Society of America, Mr. J. S. Diller read a paper on sandstone dikes in California, which, with its illustrations, forms a very attractive issue of the Society's memoirs.*

Within a short time I have seen two sandstone dikes in northwestern Nebraska. One is that referred to above as mentioned by Professor Hicks, which he had already described to me. The second is only half a mile from the first, and possibly may be a continuation of it. I have seen the first on two different occasions, taking measurements both times; the second one was visited only once, on the same date as the second visit to the first. On this occasion I was accompanied by Professor

FIGURE 18—*Sandstone Dike number* 1.

Culver, who filled the chair of geology in the university of South Dakota. So far as the measurements are concerned, Professor Culver is responsible as much as myself. The general description he can verify.

The town of Chadron is situated on the line of the Fremont, Elkhorn and Missouri Valley railway, and lies immediately under the heights of Pine ridge, where the harder Tertiary beds of this region are seen over the softer clays and marls forming the "mauvaises terres," which, beginning under Pine ridge, stretch away toward the north and east and, with occasional cappings of the harder beds, become the "bad lands" proper of South Dakota. Between Chadron and White river, however,

* Bull. Geol. Soc. Am., vol. 1, 1890, pp. 411–412, pls. 6–8.

there is but little of harder mortar beds, the deep ravines being almost entirely in the softer marls and clays. In places they are cut down to Cretaceous shales, probably here of the Montana group.

Directly southward from the western part of the town of Chadron, and at a distance of a little over two miles, or just over the ridge (from which the entire valley of White river and the labyrinth of "bad land" ravines are visible), and just a little to the left of the road running northward, is the first dike, or number 1. It is in the upper part of a ravine, which joins many others near by. It is so inconspicuous that it may be easily missed, yet was once much better developed than now and had the name of the "*natural wall*." Notwithstanding this name, there is a very

FIGURE 19—*Eastern End of Dike number* 1.
Showing that the dike did not reach the top of the bluff.

common impression that it is the work of human art, and was made by ancient Chadronites to corral the buffalo. But a wall it is, stretching straight across a ravine whose width is only three or four feet greater than the exposed length of the dike. It is said that early settlers saw it at least four feet high in the bottom of this ravine.

The dimensions obtained in June last were as follows: Length of the wall (across the ravine), 120 feet; average width, 8 inches; range in width, 6 to 10 inches. There must be added to this thickness from five to ten inches for a vertical laminated accompaniment which varies from 2½ to 5 inches thick on each side of the wall. The dike is almost perfectly straight, and trends N. 48° E.

The structure of the dike is such as fully to justify the term "wall." There are both vertical and horizontal lines of fracture, the former being at right angles to the line of the wall. Thus it breaks naturally into blocks, which are all rectangular. The material is sandstone.

The wall is unmistakably a dike. When the exact age of these White river beds is determined, the age of the dike will be known. It does not on either side reach the top of the ravine, and a bluff of much greater elevation a few hundred feet away shows no sign of its presence; so it may be definitely regarded as having been intruded before the completion of the deposit of the soft clays and marls. One of the evidences of intrusive character lies in the structure of the laminated sheets on

FIGURE 20—*Dike number* 2.

either side of the dike. In these the laminæ furthest from the dike are more argillaceous than those inside, and the inside laminae are decidedly grooved, with vertical ridges, and grooves to correspond, on the sides of the wall itself. The laminated structure on either side is from $2\frac{1}{2}$ to 5 inches thick, and separate laminae vary from one-eighth to five-eighths of an inch in thickness.

Half a mile in a westerly direction is dike number 2. In general, it is similar to number 1, but there are minor differences. It also crosses a ravine, which is narrower than the other; and the dike appears to be the cause of this, as it seems to have checked erosion, particularly on the western side. Its exposed length is 100 feet; its average thickness is nearly uniform at 13 inches. The vertical laminated

structure on either side has an average thickness of 3 inches. The blocks into which the wall is broken are short in proportion to thickness, and many might be called cuboidal. The stone, too, is harder than in number 1. The direction of the dike is N. 70° E.

If the lines of direction of the two dikes be continued, they cross a little nearer to number 1 than number 2, and at an angle (as seen from the above figures) of 22 degrees. Running these lines without surveying instruments, this angle was obtained as 25 degrees. Considering the distance apart and the smallness of this angle, it might be possible that the two exposures are really parts of one curved dike.

FIGURE 21—*Dike number 2.*
Showing characteristic "mauvaise terre" erosion.

Professor F. R. Carpenter, of Rapid City, South Dakota, a fellow of this Society, has had the following analysis made by Mr. Barnett, one of his assistants. The analysis is of a piece from dike number 2:

SiO_2	77.84
Al_2O_3	13.09
Fe_2O_3	1.26
CaO	3.41
MgO	tr.
H_2O	3.20
	98.80

These dikes may be related to the phenomena of mud volcanoes, as they were certainly intruded from below; and they may be expressive of the closing period

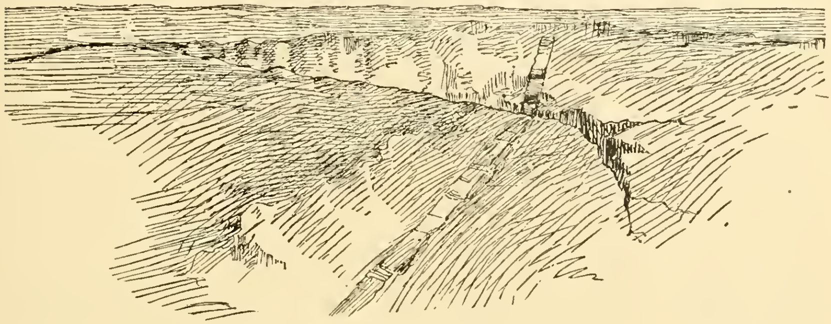


FIGURE 22—*General View of Dike number 2.*

of the Black hills uplift. We do not desire here to enter into this question, but simply contribute the facts for future study of what may fairly be called a new subject.*

Mr. Hay's paper was discussed by C. R. Van Hise and J. E. Wolff.

Mr. Gilbert resumed the chair, and after announcements declared the Society adjourned to the evening session.

EVENING SESSION OF MONDAY, AUGUST 24.

The Society reconvened at 8 o'clock p. m., the acting President, Mr. G. K. Gilbert, in the chair.

Some announcements were made, after which the following paper was presented:

SOME RECENT EXPERIMENTAL REPRODUCTIONS OF SCOTTISH MOUNTAIN STRUCTURE.

BY HENRY M. CADELL, ESQ., OF BO'NESS, SCOTLAND.

This paper was illustrated with colored charts, and was followed by a paper of similar character, illustrated with lantern views, entitled:

MECHANICS OF APPALACHIAN STRUCTURE.

BY BAILEY WILLIS.

The papers of Messrs. Cadell and Willis were discussed together by J. E. Wolff, Joseph Le Conte, C. D. Walcott, and the authors.

* After the meeting the writer was informed by Dr. Holst that there are similar dikes in Sweden, and Professor Hill states that something of the same kind exists in Texas, and there appear to be some in the "bad lands" of South Dakota.

A third paper was then presented, on—

MUIR GLACIER AND ITS VICINITY.

BY H. P. CUSHING.

This paper was illustrated with lantern views, and is published in *The American Geologist*, volume viii, 1891.

The Society then adjourned.

Session of Tuesday Morning, August 25.

The Society assembled at 10 o'clock a. m.; acting President Gilbert in the chair.

Professor Edward Orton, in behalf of the special committee appointed on August 24, presented the following report:

EULOGIUM OF ALEXANDER WINCHELL.

The Geological Society of America hereby puts on record the expression of its profound sense of loss in the removal by death from its councils, its service, and the honors which it has to bestow, of one of the most efficient and influential of its founders, Dr. Alexander Winchell. Prominent in all of the preliminary work that led to the organization, he has been an office-bearer of the Society from the date of its establishment, and at its last annual meeting he was made its president.

Our sense of loss is due to the fact that in the death of Dr. Winchell, stricken down as he was in the fulness of his productive power, geological science loses one of its foremost representatives in this country. Forty years of arduous and uninterrupted work stand charged to his credit in the records of American geology. During this period the science itself, in common with all other branches of organized knowledge, has been greatly transformed. The older subdivisions have been deepened and extended; new subdivisions have been established. To all of this progress Dr. Winchell was from the first an important contributor; with all of it he kept abreast.

Dr. Winchell's first important work was done in stratigraphy and paleontology. As state geologist of Michigan, he helped to work out, in an important and interesting section of the St. Lawrence basin, the order of the geological series, and he worked it out so well that from that time forward he who runs may read. In his later years he took an active part in the study of the unsolved problems of the Archean system, and

all of the problems, structural and historical, he has treated lucidly and soberly and to the enrichment of our literature.

There is, however, another division of our science in which Dr. Winchell's untimely death will be most severely felt. Who among us is prepared to treat with equal scope and breadth, with equal mastery of all that has been done by others in this abstruse field, the large questions of cosmical geology—questions which, though requiring for their discussion the methods and resources of other divisions of science, must always find their most natural reference within our own domain?

In the death of Dr. Winchell we lose an accomplished and eloquent teacher of geology, whose oral instruction has inspired many thousands of educated men, in all professions and callings, with deep interest in and profound respect for this division of knowledge, while his text-books have marked a new departure in the elementary teaching of geology, to the great and lasting advantage of the science.

To all this must be added his remarkable ability and success as a popular expounder of the doctrines of geology. No man since the days of the elder Agassiz has done so much to familiarize the more intelligent portion of our American communities with the great deductions and the established results of our science.

Another service, and one of incalculable value, though confessedly incapable of precise definition, Dr. Winchell rendered to us all in this line of public exposition. Unquestionably the most important contribution of our day to geological science is the doctrine of organic evolution, as presented by Darwin and his successors. But the first enunciation of this doctrine naturally awakened distrust and even bitter hostility among a large class of our people, because of its apparent incompatibility with some of their most fundamental convictions and beliefs. To disregard the sincere apprehensions of this great class, comprising as it does so much of the moral and intellectual force of the body politic, would be heartless. To mock at its fears, ill founded though they were, would be worse. What worthier service to science and the community than to disarm this hostility by showing that the evolutionary philosophy, so far from degrading and dishonoring man, makes him in a peculiar sense the head and crown of the creation? We are indebted to Alexander Winchell more than to any other representative of science for the rapidly growing liberality and enlargement of thought of the more serious-minded portions of the community in regard to these questions. From the lecture platform, in magazine and review and newspaper, as well as in more formal and permanent fashion, Dr. Winchell stated and defended with marked ability, courage, and persuasive power

this the most characteristic and far-reaching doctrine of modern geological science. His last public service was in this very line.

In addition to the features of the life and work of our departed colleague to which we have already called attention, at least by implication, viz, his breadth and largeness of view, his hospitality to new truth, and his courage in advocating it, we must not fail to name the personal qualities that have insured for him a lasting place in our affection and regard. In his candor, his fairness, his courtesy, he approached the ideal of the searcher for the truths of nature; in his devotion to his work he literally knew no limit, save that which the narrow house and the long sleep impose upon us all.

To sum up in a word, Alexander Winchell's work constitutes an honorable section of American geology, incorporated in its growth and built into its foundations, and thus sure to bear fruit for all time to come, while the spirit in which he did his work insures to his name honor and regard on the part of all who knew him.

EDWARD ORTON,
C. R. VAN HISE,
C. A. WHITE,
Committee.

I. C. White moved the adoption of the resolution by a rising vote.

Dr. Charles A. White, in seconding the motion, spoke as follows:

For nearly thirty years it was my good fortune to feel assured that my name had a place upon the list of Alexander Winchell's friends. We each, unknown to the other, began our geological studies upon closely related formations, and soon after the publication of my first papers he called upon me at my home to confer with me upon the subject of our studies. This was the beginning of our acquaintance, and from that time until his death my esteem for him steadily increased.

It is not necessary for me to add anything to the eulogy that has already been spoken of him, but I wish to avail myself of this opportunity to add my personal testimony to his virtues in a second to the motion just made.

Professor Winchell was a man of strong personality, but he was also strongly sympathetic. He not only possessed all the cardinal virtues of the ancients—justice, prudence, temperance and fortitude,—but he was kindly, generous and charitable. His love for his family and kindred amounted almost to a passion, and yet his kindness of heart extended to all with whom he came in contact. He was deeply and sincerely religious, but bigotry was entirely foreign to his nature. He was deliberate and careful in forming his opinions, and once formed he held

them with firmness; but in upholding them he never descended to personalities, and no word was ever uttered by him that left a sting on the memoroy of his opponent, even when vanquished. He was wise and learned, a kind and true friend, an exemplary citizen, and, best of all, an honest man.

The motion was unanimously adopted by a rising vote.

The first title on the printed program was passed over, and the following paper was presented:

THE *EURYPTERUS* BEDS OF OESEL AS COMPARED WITH THOSE OF NORTH AMERICA.

BY DR. FRIEDRICH SCHMIDT, OF THE ACADEMY OF SCIENCES, ST. PETERSBURG, RUSSIA.

(*Abstract.*)

One of the uppermost divisions of the Silurian system of the state of New York and western Canada, the Waterlime group, is characterized by a peculiar fauna of large crustaceans, *Eurypterus*, *Pterygotus*, *Ceratiocaris*, etc. It has already been said by Sir Rhoderick Murchison that this fauna shows a great resemblance to similar crustacean faunas of the uppermost Silurian strata of Great Britain, the shales of Lesmahago in Lanarkshire and in some places near Ludlow, where the crustaceans are associated with a small *Lingula*, the characteristic *Platyschisma helicites*, and divers fish remains.

But still greater seems to be the resemblance of the American Waterlime fauna to our *Eurypterus* beds of the island of Oesel, in the eastern Baltic, because the most characteristic forms of both localities are two very nearly allied species of *Eurypterus*—the *E. remipes* of America and the *E. fischeri*, Eich., with us. Besides the *Eurypterus*, we have a large *Pterygotus*, the *P. osiliensis* (aff. *P. bilobus*, Salt.), two species of *Bunodes*, Eich. (connected with the English *Hemiaspis*), and a large *Ceratiocaris*, the *C. nötlingi*, similar to the *C. maccoyanus* of America.

Last summer a local collector, Mr. Simonsohn, of Wenden, in Livonia, found the metastoma of the genus *Dolichopterus*, hitherto only known from the American Waterlime; and so the resemblance between the American and Russian eurypterids becomes greater.

The most famous locality of our *Eurypterus* beds is Rootzikull, near Kielkond. Here, besides the crustaceans, we have also found fish remains—two cephalaspidean genera, *Thyestes*, Eich., and *Trematаspis*, described some years ago by Eichwald, Pander and myself. Now we have better specimens, which will be described soon by Dr. I. Rohon, of St. Petersburg, who has also lately described the first real fish remains of the Lower Silurian, from the greensand at the base of the Silurian, at Wessiks.* These *Eurypterus* beds, consisting mostly of yellow dolomitic flagstones, are overlain by thin marly deposits, only a few inches thick, filled with small

*Some of the Esthonic country people at Rootzikull know how to get the *Eurypterus* out of the limestone, and Mr. Simonsohn, who now spends every summer there, will be ready to furnish geologists with good specimens.

specimens of *Leperditia* (*L. angelini*), *Platyschisma helicites*, Sow., and small scales of fishes mostly belonging to the genus *Cœlolepis* of Pander.

With us the *Eurypterus* horizon forms the base of our uppermost Silurian stage, *K*, according to my arrangement of our Russian Baltic Silurian in Estonia and the island of Oesel,* and can be followed all over the island, from west to east, at the boundary line between the stages *J* and *K*, the former corresponding to the Wenlock of England and the Niagara limestone of North America.

The *Eurypterus* beds are overlain by a yellow limestone or dolomite containing *Stromatopora*, *Favosites*, *Syringopora reticulata*, *Labechia conferta*, and other corals (but not *Halysites*, which is restricted entirely to lower horizons of the Upper Silurian), besides *Murchisonia cingulata* and allied forms, *Orthoceras imbricatum*, *O. angulatum*, and *O. gigantea*, *Ilionia prisca*, *Megalonus gothlandicus*, *Meristella didyma*, *Leperditia grandis*, and other fossils. In the southern and southwestern portions of Oesel there follows a band of gray limestone with *Atrypa prunum*, *Spirifer elevatus*, *Chonetes striatella*, numerous specimens of *Tentaculites* and *Beyrichia*, peculiar forms of *Calymene* and *Proetus*, and in some places with a profusion of spines (*Onchus*) and scales (*Tachylepis*, Pand., or *Ghelodus*, Murch., *Oniscolepis*) of fishes described by Pander in 1856. This gray limestone, which is known among the northern German erratic bowlders as the *Beyrichia* limestone, I regard as the highest beds of Oesel, though actual superposition has not been observed. Both the gray and the yellow limestones correspond very well with the Ludlow of Great Britain. The yellow limestone containing also *Eurypterus fischeri* is very clearly recognized on the eastern side of the Swedish island of Gothland, near Oestergarn, and also on the Dniester in Podolia (southern Russia), from which locality the *Eurypterus fischeri* was originally described.

With regard to my Silurian country of Oesel, I have no reason to enter into the Hercynian question, because, as already stated, our uppermost Silurian strata correspond exactly to the typical Ludlow of England. Our Silurian is unconformably covered by the middle Devonian ("Old Red sandstone"), since in the east the Cambrian and lower Silurian strata are situated directly below the "Old Red sandstone," just as in the west they lie below the upper Silurian deposits.

The purpose of this communication is to attract the attention of American geologists to the striking resemblance of the fauna of our Baltic *Eurpterus* beds to the Waterlime fauna of North America, and to express the hope that our cephalaspidean fishes, or something like them, would be some time found in this country.

In coming to America it was my wish to become more intimately acquainted with the different Silurian stages, and especially with those adjacent to the Waterlime group, *i. e.*, with the Onondaga and Guelph limestones on the one side and the *Tentaculite* limestone on the other. It would perhaps be possible to find other connecting links in the development of life in both countries.

Lately I have had the opportunity of seeing the Waterlime and the *Tentaculite* limestone at Oriskany falls in the state of New York. Both deposits together correspond very well to our uppermost eastern Baltic stage *K*. But, beyond this striking resemblance of the Waterlime crustacean fauna and that of our *Eurypterus* beds, I cannot yet compare strictly the other deposits of my uppermost Silurian zone in this country. That will perhaps be possible after returning from our long excursion, when I shall have perhaps the opportunity of seeing more of the Silurian strata in the United States and Canada.

*See Quar. Jour. Geol. Soc., Nov., 1882, p. 514.

The second paper read was:

ON THE MARINE BEDS CLOSING THE JURASSIC AND OPENING THE CRETACEOUS, WITH THE HISTORY OF THEIR FAUNA.

BY PROFESSOR ALEXIS PAVLOW, OF THE UNIVERSITY OF MOSCOW, RUSSIA.

As regards the Paleozoic system, comparative or systematic geology has recently made great progress, thanks to the excellent work of American and European geologists; the correspondence of stages in the two continents has been established, and the history of the Paleozoic seas is, in its principal features, the same for the whole northern hemisphere. The case is different for the Mesozoic beds, especially for those that close the Jurassic system and begin the Cretaceous. A kind of separatism is observed in them: In the Anglo-Parisian basin and in part in Germany the upper stage of the Jura is called by the name of Portlandian, and the Cretaceous is held to begin with the Neocomian; in the southern part of France, in Spain, and in the Alps it is the Tithonic stage that tops the Jurassic, and the Tithonic in its turn is overlain by the Berrias; in northern England the boundary between the two systems passes through a series of beds called the Speeton clay; in Russia, the name of Volgian stage has been created to designate the upper beds of the Jura and the lower beds of the Cretaceous. Every country claims at this epoch its peculiar geologic history, and the geologists of the various countries are busy describing the peculiarities of the beds deposited at that epoch. But what has become of the vast ocean of the globe as it then existed? Do we know the faunal history of that ocean, a history independent of the local episodes spoken of in describing these stages? What has become of the cephalopoda, the ammonites and the belemnites, our faithful guide in the parallelization of the Mesozoic beds? These are the questions that have long interested me, and I am happy to be able to communicate to this distinguished Society some results of my studies.

I shall try to be brief. I am convinced that the separatism of which I spoke is not a consequence of the minute comparison of these stages, but rather a result of the lack of comparative study, of the absence of a well concerted synonymy of the species, and of the incompleteness of researches on the development of the faunas. I have undertaken this study for belemnites and the ammonites, and the results which I am going to set forth will demonstrate, I hope, its importance for stratigraphic questions.

I had at my disposal, in my studies, a large collection from Speeton and Lincolnshire, by Mr. Lamplugh, the collections of the museums of York and Scarboro, some forms from the South Kensington Museum and from the museum of the Jardin des Plantes at Paris, and a large collection of fossils preserved at the museum of Moscow.

In studying minutely the characters of the belemnites of the groups *Excentrici* and *Absoluti*, and of the English group *Oweni*, which are the most numerous in the beds spoken of, I was able to distinguish among them three great branches, each developing in a certain direction. The neighboring species that enter into these branches pass insensibly into one another, so that the limits between them are more or less arbitrary, while in the case of the typical forms they are perfectly well distinguished. The most interesting fact from a geologic point of view is that these branches, in the various countries, pass through beds developing in a parallel manner, and we observe in England and in Russia that the same phases of development appear

almost simultaneously; and, vice versa, a certain phase of development indicates a certain geologic epoch, as if it were a single fauna developing in some particular direction and presenting some local deviation of small importance, such as the predominance of this or that species and the comparative rarity of another.

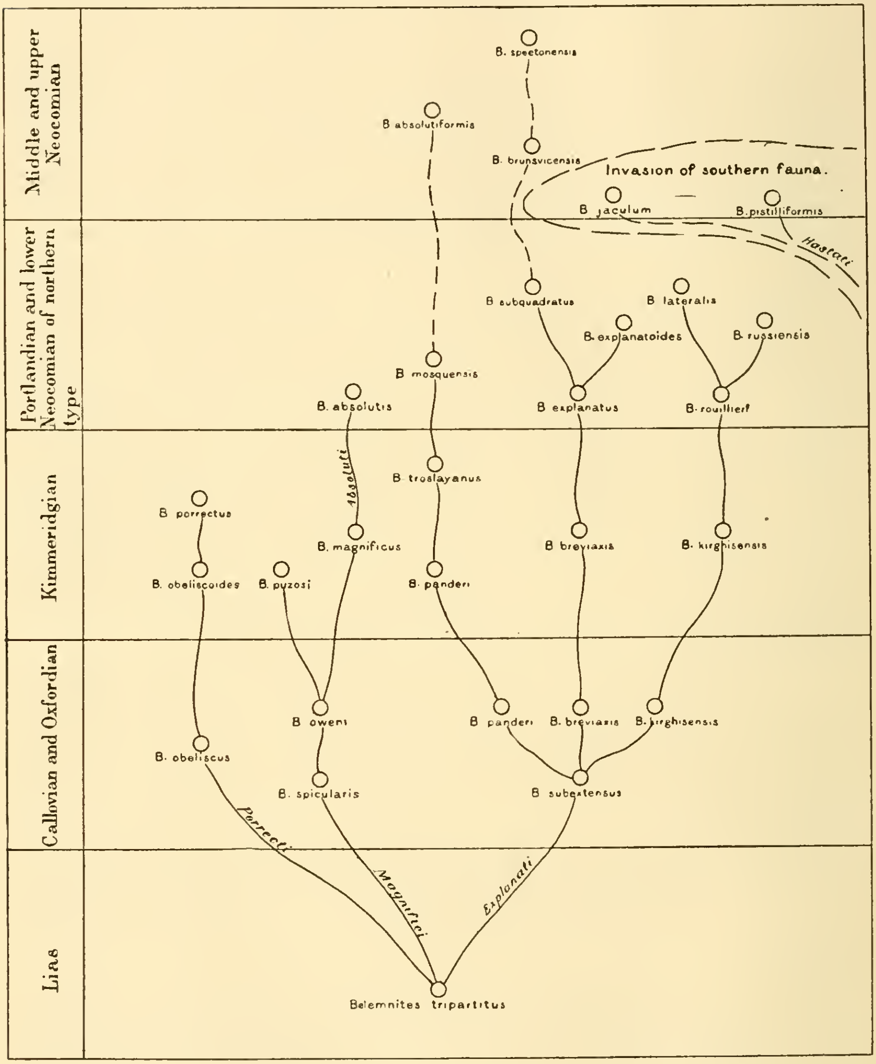


FIGURE 23—*The Development of the belemnitic Fauna at the End of the Jurassic and the Beginning of the Cretaceous.*

I now proceed to characterize these branches, whose relations are indicated in the accompanying diagram. The first comprises the greatly elongated forms, such, for example, as have been described by Phillips under the name of *Belemnites obelis-*

cus, *B. porrectus*, etc. I add to them some other species and designate that branch by the name of *Porrecti*. It commences in the Callovian by smooth forms without ventral groove; in the Oxfordian and the Kimmeridgian we find the same elongated form with a short ventral groove below; while in the upper Kimmeridgian these belemnites have a ventral groove which passes from one end to the other.

The second branch comprises the thicker and less conical forms. It begins in the Callovian by *Belemnites spicularis*, a form almost devoid of a groove, which in the Oxfordian gives rise to *B. oweni*. The latter is gradually transformed into *B. magnificus*, in which the groove or ventral flattening is very distinct and occupies about one-half of the rostrum (guard). All the belemnites mentioned are common in Russia and in England in the successive beds from the Callovian to the Kimmeridgian. *B. magnificus* gives birth to *B. absolutus*, the culminating form, which is widely spread and very common in the upper beds of the Jurassic of Russia. I designate this branch by the name of *Magnifici*.

The third branch, which I call *Explanati*, is the most complicated. Starting from a Callovian branch, *Belemnites subextensus*, we see three sub-branches (twigs) developing each in its own direction. One comprises the thick-set and obtuse forms (*B. kirghisensis*, *B. lateralis* and *B. russiensis*), while the other begins by *B. breviaxis*, which is modified into *B. explanatus*, and this in turn passes into *B. subquadratus* and a kindred species, *B. explanatoides*. The third sub-branch begins by *B. panderi*, which is transformed into *B. troslayanus*, the predecessor of *B. mosquensis*. I am now convinced that *B. panderi*, and perhaps some allied species, exist in America, where they are known under the name of *B. densus*. As in the old world, so in America, they characterize the boreal provinces of the Jurassic sea. The history of the development of this sub-branch is the most interesting. In northern England these forms are developed continuously up to a certain horizon, namely, the summit of beds *D*, called Portlandian, but which are also considered by some geologists as lower Neocomian. Above this horizon, in the beds *C*, these forms disappear abruptly, and are replaced by belemnites of quite a different origin, *B. pistillirostris*, *B. jaculum*, and other representatives of *Hastati*, which appear simultaneously. Mr. Lamplugh, during several years of assiduous research at Speeton, found only two specimens belonging to the preceding group. But already in the upper part of beds *C*, and above these beds, the *Hastati* become less and less numerous, and we find once more the belemnites exhibiting the characters of the Jurassic group *Explanati*, but they are the more or less distant descendants of the Jurassic forms.

The *Explanati* were evidently dwellers in the boreal part of the Jurassic sea. They are known in Russia, in northern England, in North America (Queen Charlotte islands and Dakota). They are also found in France and in southern England, but they are rarer in those regions. The *Hastati* are the southern forms. They are wide-spread in the Alps, in southern Europe, in the Caucasus, in India, and in Madagascar. Thus we observe at Speeton, at a certain horizon, the invasion of the southern fauna in the northern sea, and the replacement of the boreal fauna by the southern fauna. But the predominance of the southern fauna was not of long duration; already in the upper Neocomian, and perhaps also in the middle, conditions changed, and the descendants of the boreal forms come to regain the dominion of their ancestors. In Russia the history of the faunas is less complicated, because the southern colony did not exist there, except in the Crimea.

The history of the belemnites which I have just set forth is only an example affording us a glimpse into the history of the Mesozoic seas at the epoch in question.

Certain groups of ammonites present no less striking examples, proving that a climatic change took place in the seas of middle latitudes in the northern hemisphere at the beginning of the Cretaceous period. The characteristic cephalopoda of the lower Cretaceous of middle Europe are well known. They are especially the belemnites of the group *Hastati*, the flat belemnites, the ammonites related to the group of *Olcostefanus astieri*, the representatives of the genus *Olcodiscus*, and some hoplites.

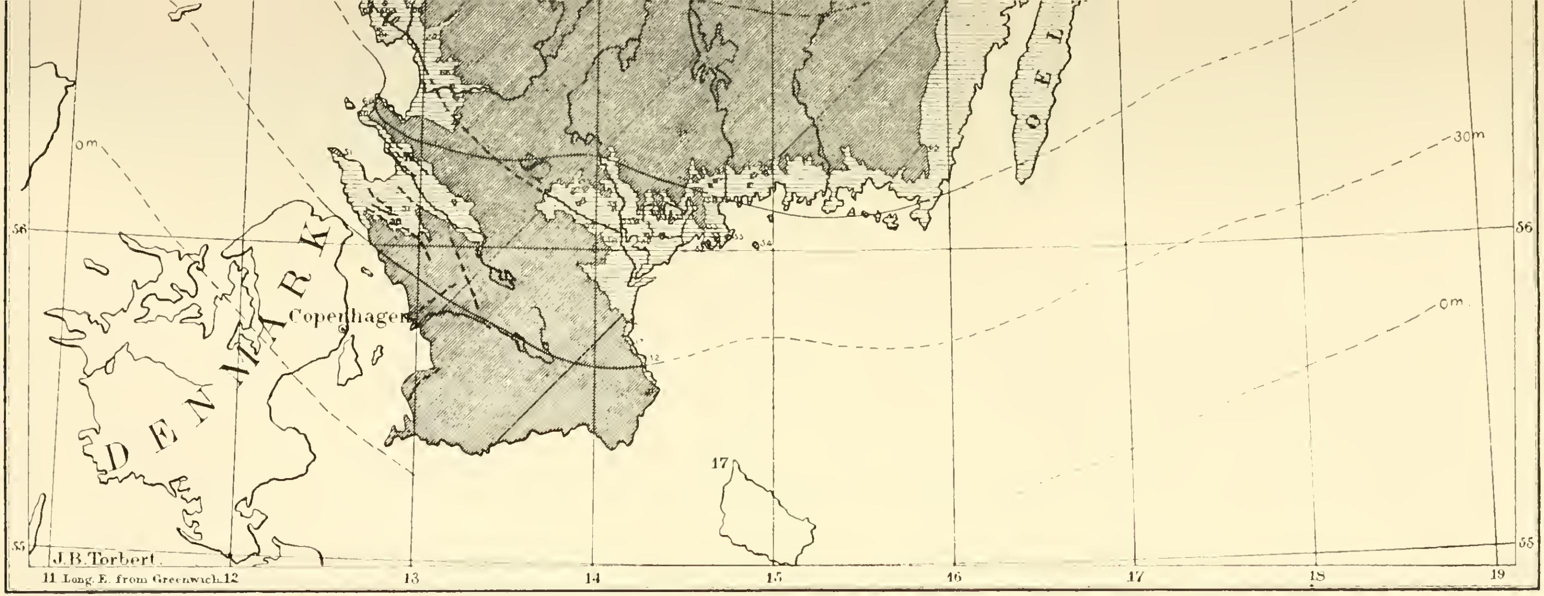
As regards the belemnites, we know already that they are southern forms. Fixing our attention on *O. astieri*, and its kindred, it is not difficult to see that it is a southern form. We know it in India and in South Africa (*A. atherstoni*), and the British museum contains a very good specimen from South America. In Russia we know these forms in the Crimeo-Caucassian region. In northern England they appeared with the *Hastati*, to replace the boreal fauna, and to inaugurate the typical Neocomian. The same thing might be said of the representatives of the genus *Olcodiscus* and of some hoplites characteristic of the Neocomian. Thus the study of the cephalopoda of the upper Jurassic and of the Neocomian demonstrates that the forms are the same in central and eastern Russia, in northern England, in Germany, and, in part, in southern England and in France; that in the last two regions the fauna presents a mixed character, the boreal forms being there found together with the southern, the latter becoming more and more numerous as we go southward. The boundary separating the two faunas does not always remain the same. Certain epochs may be pointed out when the southern fauna advanced northward, driving back the boreal fauna, which afterward resumed its sway. This complicates the series of the beds which we are studying as well as their history, and we are often embarrassed in regard to the establishment of the exact correspondence of the beds. But, on the other hand, we recognize horizons common to the two great regions of the globe, and we are in condition to establish the strict correspondence of the beds and to decipher the geologic history of the whole world, provided we do not neglect the systematic paleontologic studies which indicate the development of the important groups of the animal kingdom, such as the belemnites and the ammonites.

I have demonstrated that an interesting change took place in the physio-geographic conditions in a vast region, extending from eastern Russia to England. It cannot be said that this was due to a local oscillation of sea-level. Not only is this true, but the same forms of cephalopoda are found in the Jurassic and Cretaceous beds of America. There, too, the two faunas, the southern and the boreal, may be distinguished. The regions where these faunas meet (California, for example) present difficulties to the observer, but they promise at the same time to yield a uniform and general classification for all countries, and to render intelligible and simple the general history of our globe—that mysterious history which thus becomes more and more attractive.

American geologists have before them the same scientific problems that engage our attention in Europe. Their solution will be speedier and easier if we work together. This suggested to me the idea of setting forth before you the direction and some of the results of my studies. Our science knows not the artificial boundaries that separate nations, nor will it recognize natural boundaries, such as oceans. The history of our globe has for a long time been the common work of all nations and of all peoples, just as the globe itself will one day be the common heritage of humanity, one and united.*

---

*For further details, see Bull. de la Soc. des Naturalistes de Moscow, 1891.



17 - - - - Points where the late glacial marine boundary is levelled (in meters).

30m - - - Isanabases lines of equal upheaval of the land.

- - - Terminal moraines, partly from the earlier glaciation.

- - - Land raised above sea level since the ice age.

- - - Land raised above sea level before the ice age.

Map of the late glacial marine area in Southern Sweden.

By

Gerard de Geer.

1891.


Christiania
Stockholm
Gothenburg
LAKE WENER
LAKE WETTER
GOTLAND
240m
210m
180m
150m
120m
90m
60m

The third paper read was—

QUATERNARY CHANGES OF LEVEL IN SCANDINAVIA.

BY BARON GERARD DE GEER, OF THE GEOLOGICAL SURVEY OF SWEEDEN, STOCKHOLM.

Although I have not had sufficient time to prepare an elaborate lecture, I have thought it appropriate on the present occasion to place briefly before the Geological Society of America a synopsis of our present knowledge in regard to the Quaternary changes of level in Scandinavia, inasmuch as there are yet prominent geologists who deny the existence of continental upheaval. The conditions found in Scandinavia, however, seem to afford good evidence of such changes. Moreover, this seems to be the very time to place before you for comparison the analogous phenomena in northern Europe, since so extensive and excellent investigations in relation to Quaternary changes of level in North America are in progress just now. And finally, it was my good fortune, immediately before leaving Sweden, to complete my observations in such a way that it has been possible to give a general view of the question and to present a somewhat detailed map of the changes, so far as southern Sweden is concerned.

It has been long known that raised marine deposits with an arctic fauna occur over the latest moraines in Scandinavia, and in most text-books they are said to be found as high as 500 feet in Sweden and 600 feet in Norway; but exact determinations of the uppermost marine boundary itself have not been given, thereby allowing too much latitude for speculation in regard to the cause of the present high altitudes of these deposits. It is true that the eminent French physicist, Bravais, half a century ago came to the conclusion that two elevated rock-terraces in northern Norway examined by him are not horizontal but descend toward the north, the upper one more so than the lower; but his opinions have been doubted more and more, and several geologists, even from Scandinavia, are less inclined to believe in an unequal upheaval of the earth's solid crust than in changes of the level of the changeable sea.

In Sweden no such rock-terraces as those of Norway, which are visible for miles and miles, are found, nor are there, as a rule, long, continuous beaches; for the wooded country is very hilly, so that it is not easy to connect the beaches and find out whether the changes have been unequal or not. It seemed probable, however, that the upper boundary of the marine deposits might be synchronous at the different localities, and I have, therefore, since 1883, attempted to determine altitudes as often as an opportunity was offered. This assumption I have recently been able to substantiate by the observation that the maximum of depression did not occur quite simultaneously with the ice-covering, but somewhat later, as shown by channels cut through the summits of terminal moraines by glacier rivers coming down from the ice-border at about 93 per cent of the height of the upper marine boundary. Hitherto I have seen such channels of erosion only about the northernmost extension of the terminal moraines on the map, just in the vicinity of the Norwegian frontier; but it is probable that they occur in many other places, and, if so, it will be possible more accurately to determine the level of the sea at the margin of the receding land-ice. At present it is already evident that at the maximum depression no ice could, at least in southern Sweden, obstruct the synchronous formation at all points of the uppermost beach.

The method which I have adopted for determining the marine boundary is as follows: I first select on the topographic map hills of sufficient altitude to make it certain that they were above the marine boundary under all conditions. They must be mainly covered with moraine matter, in which the breakers usually leave the most easily distinguished traces. The situation has to be open and the ground moderately inclined, so as not to interfere with the action of the breakers. Finally, such localities must be selected as are situated in the neighborhood of points already leveled, from which I could start when ascertaining the level of the marine boundary. This, in different places, is of a somewhat different appearance. At the promontories it is often formed as a cut terrace with a more or less steep bluff, at the base of which sometimes only the greater bowlders are left just as the bowlder pavements described by Mr. Spencer, and when the erosion of the breakers has been very strong the rock is laid bare up to the very uppermost marine limit. At more protected points the limit is sometimes marked by built terraces and beaches. In ascertaining the level of the cut terraces I have always taken that of their base, while of the others that of their summit, which, in general, is a few decimeters lower. In every locality the mean is taken of several points at the boundary, and the probable error, I think, will hardly exceed one meter, being usually only a few decimeters. Most of the points (now amounting to about 60 or 70) are determined with good hand-levels, some with spirit-levels, and only two with aneroids.

The first points which I happened to determine were situated in eastern Scania, in the direction of the strike of the old deformed geoid, so that the heights of the different points were nearly equal, viz, some 50 meters. Somewhat more toward the south I afterward obtained successively 48, 42, 37, 32 and 21 meters, and that in quite open localities, in which are found well-developed series of sea beaches below the marine boundary, while immediately above the same the moraine matter does not show the faintest trace of any washing by the sea. It was therefore evident that it is necessary to assume an unequal uplift of the land in this the southernmost part of Scandinavia. This led me to the conclusion that not only were the observations of Bravais in the Altenfjord correct, but that in all probability the same law would be found exemplified all over the Scandinavian peninsula. In order to investigate this question further, I attempted in 1888 to plot on a map, published in the Transactions of the Geological Society of Stockholm for that year, such approximate determinations of the upper marine deposits in the various parts of Scandinavia as were available at that time. I thereupon connected the various points of equal deformation by lines, as Mr. Gilbert had already done for Lake Bonneville. For the sake of brevity, I named these lines *isanabases* or *isobases.*

This first attempt to thus put together the facts showed already most clearly that all the points could be grouped in one single system, all the higher localities appearing in the central parts of the land and all the lower ones in the peripheral parts, in the south as well as in the west, the east and the north, in such a manner that the isanabases formed concentric circles. The phenomena, thus being of purely local nature, can have nothing to do with general changes in the level of the sea. Furthermore, as the highest marine deposits are situated in the central parts of the land as high as 260–270 meters above the sea, it will be easily seen that the very much reduced remnants of the original ice-sheet which could possibly exist when the sea in late-glacial time reached so far could not—with respect to their local attraction—have played any rôle worth mentioning in the explanation of the raised beaches; and the more so, when the figures we get when starting in the calculation

from the maximum ice extension during the earlier and greater glaciation are even then about ten times too small. We are thus obliged to admit that these shore-lines have been uplifted through a real continental elevation of the earth's crust.

During the last four years I have determined a considerable number of points, and these have afforded good evidence corroborative of the opinions expressed in my first paper. Thus the isanabases were found to conform with the limits of the Scandinavian Azoic territory, and, according to the very latest determinations, not only in a general way but also in many details, the isanabases, for instance, forming a great convexity around the southern extension of Sweden as well as small ones around several promontories. On the other hand, they form concave lines around lake Wener, as shown on the accompanying map. Though not yet quite settled, the case is probably similar with regard to lake Wetter, the second largest lake in Scandinavia. These lakes, therefore, have not risen quite so much as the surrounding country. This fact seems to indicate that our larger lakes were originally more depressed than their surroundings during an earlier stage of the ice age, thus probably accounting for their formation.

The coincidence between the area of upheaval and the Azoic territory may possibly be explained by assuming that this territory, which is an old tract of erosion, has also been one of continental upheaval which subsided during the ice age, for the greater part perhaps in consequence of the considerable ice-load, again rising after the release from the latter, though not to its former altitude. Before this rise, several straits crossed the central portion of Sweden, and through these *Yoldia arctica* and *Idothea entomon* certainly immigrated to the tracts around Stockholm, near lake Mælar. These straits were gradually uplifted above the sea-level, and the Baltic sea became a true fresh-water lake. To this time belong probably the beaches in open situation, although containing such fresh-water forms as *Ancylus fluviatilis*, *Pisidium*, *Planorbis* and others, which have been found in Estland, Gotland and Oèland by Messrs. Schmidt, Munthe and Holm.

As shown by peat-bogs, river channels, and deposits of littoral mollusks, all now submarine, the rise of the land continued until some tracts, at least, were lifted to about 30 meters higher than at present. Then a new continental depression commenced, the uppermost limit of which I have had the good fortune to discover and to determine at some twenty points in southern Sweden. This limit is marked in many places of level ground by unusually well-developed beaches and terraces, below which marine deposits with a true post-glacial fauna—containing the species characteristic of the kitchen-middens of Denmark—are found, indicating salter and probably somewhat warmer water than at present.

The post-glacial limit is situated in the middle portion of the country about 50 meters above sea-level, becoming gradually lower towards the peripheral parts until no evidence of any upheaval whatsoever can be discovered. While this post-glacial depression is of a special interest in that its maximum was probably contemporaneous with the beginning of the neolithic stone age in Scandinavia, it also shows that a depression has taken place which cannot be directly connected with the ice-load. In the meantime, it cannot yet be decided whether this subsidence of the land between the two upheavals has occurred even in the central parts of the country and has been proportionate to the amount of these, or is perhaps only a peripheral phenomenon synchronous with a continuous elevation about the axis of uplift.

The distribution of the deformation indicated by the raised beaches is shown in the accompanying map, plate 2.

Time will not allow me to proceed further in detail. I wish only to say that I do not think we have yet reached the full solution of the difficult problem of continental elevation. On the contrary, this is not to be expected when we consider that we have scarcely more than commenced a methodical investigation; but I think that it has been shown that we have good chances of reaching the goal by the somewhat long but reliable way of induction.

The paper was discussed by T. C. Chamberlin, E. W. Hilgard, G. K. Gilbert and the author.

The fourth paper presented was on—

THE "BLACK EARTH" OF THE STEPPES OF SOUTHERN RUSSIA.

BY PROF. A. N. KRASSNOF, OF THE UNIVERSITY OF CHARKOW, RUSSIA.*

Among the problems belonging both to geology and to geography, the study of the Quaternary sediments, including the soils, is one that has for a long time attracted the attention of the votaries of these two sciences. In fact, the soils, like most of the other recent formations, have so great an influence on scenery, culture and vegetation that to know their origin, properties and distribution is as important for the geologist as for the geographer. This is the reason why I, a geographer, have come to attend the Geologic Congress and to take part in the discussions on the Quaternary sediments of the globe. The object of my communication to-day is to lay before you some recent researches on the Russian soils, which bear some relation to those of America, and which are of general interest.

In Russia the study of the vegetal soils, and especially of the "black earth," has recently attracted the attention of geologists, and it is to this study that most of our researches have been devoted. It is my purpose in the following remarks to make you acquainted with the principal results of these studies.

It is well known that the soils of southern Russia differ greatly not only from those of other parts of Russia but also of the other countries of Europe. Only the Hungarian, and perhaps some of the southern Prussian soils, have some similarity with our black earth, but these are far less characteristic than those of Russia.

This soil, which we call *chernozem*, or "black earth," has long been famous for its fertility, its black color, and its wealth in organic substances of a very peculiar character, different from those of our marsh lands. These properties have attracted the attention not only of travelers and of the natives, but also of naturalists; and, toward the end of the last century, Pallas, and shortly after, Murchison tried to explain the mode of formation and the cause of the fertility of the "black earth." Pallas looked upon it as a sediment of marine origin, formed by algæ and other organisms decomposed and petrified. According to him, the steppes of Russia were but recently abandoned by the waves of the sea. It is hardly necessary to say at this day that this hypothesis rests on no scientific proof. Neither are the soil itself and the underlying ground stratified, as are all marine formations, nor are they tocked with the fossil remains of sea animals. There is no proof that the sea covered the surface of southeastern-central Russia after the retreat of the Tertiary ocean, which took place at a remote date. It is not surprising therefore that though this

* Translated by R. Stein.

theory found adherents during the first half of the century, it was soon replaced by another.

This other theory, founded on the opinion of the people and set forth in a scientific manner by Ruprecht in 1866, has recently been confirmed by stronger proof furnished by Dokuchaef. It may at this day be regarded as accepted by most Russian geologists. According to this theory, the chernozem is nothing else than a vegetable earth formed by the roots of plants, which, in decaying, enriched with organic substances the rock on which they had flourished. It differs from our soils formed by this means only by its wealth in organic substances and in the mineral salts that accompany them. It has nothing in common with the soils of the marshes, because the humus of the latter has an acid reaction, while that of the "black earth" is neutral; moreover, it is not transformed into other substances by desiccation, as happens with the soils formed out of peat. The substances of the underlying rock or subsoil form the mineral skeleton of the "black earth," and the relative quantity of organic substances in the vertical section of that soil becomes less and less as we go down, until at a depth of about two feet it becomes zero. The "black earth" has been found on the most diverse rocks. Thus, neither its structure nor its position has anything in common with the sedimentary formations produced under water; and the remains of the solid parts of the graminaceæ scattered here and there through the mass of humus afford another proof, of no less weight, that this soil was formed by the roots of an herbaceous vegetation. This theory, accepted, as I have said, by most Russian geologists, in these general terms, leaves yet many questions in obscurity.

If you cast a glance on the soil map of European Russia you will see that the "black earth" there covers a very limited space; it is a black band that begins on the Austrian frontier, and may be followed to the Ural. Both the northwestern and the southeastern portions of Russia are entirely devoid of "black earth." Ruprecht, who was the first to give a scientific exposition of the theory of the formation of the "black earth" by the roots of plants, at a time when the theory of the glacial period had not yet become general, set forth these peculiarities in the following terms: The whole northern and northwestern parts of Russia, at the beginning of the Quaternary epoch, must have been a sea; on the waves of that sea floated the ice carrying the erratic blocks found here and there in northern Russia. The northern boundary of the "black earth" was the shore of that sea. According to him, the limit of the erratic blocks coincides with the northern boundary of the "black earth." Thus the erratic blocks in the north and the Aralo-Caspian sediments (with fossils of mollusks still living in the modern Caspian) in the southwest were by him regarded as proofs that at a time not long ago the greater part of Russia was covered by the sea. Only the region of the "black earth" was then dry land, covered, as at the present day, by steppes. At this time the "black earth" began to be formed. "In fact," says Ruprecht, "how will you explain that the region of the chernozem has a characteristic flora whose representatives are wanting in the northwest and southeast of Russia? How will you explain this depth and this wealth in humus of this vegetal earth, if observation shows that on the kurgans or mounds erected in the midst of the steppes by the nomads, most of which are more than a thousand years old, there is yet found only a layer of soil a few centimeters thick? Finally, why do these soils of the northwest and southeast, of recent origin, bear so trivial a flora, in common with Scandinavia and the Ural, while the chernozem is so rich in characteristic forms? We cannot but as-

sume that the region of the chernozem, from the earliest times, since the end of the Tertiary, was a steppe covered by a characteristic steppe vegetation under which the chernozem was slowly formed."

But this view, which to the modern geographer may seem somewhat crude, could find adherents only up to the day when the glacial theory became dominant among geologists and geographers. At the present day, after the researches of our glacialists, Krapotkin, Nikitin, and others, we know that the youngest formations bearing erratic blocks are of the same origin in our land as in Germany; that they are the moraine of the Scandinavian glacier, the traces of which are found not only in the region of Ruprecht's sea but farther southward under the "black earth," as well as in the governments of Poltava and Voronesh. Professor Dokuchaef having at the same time found several points where the "black earth" covered Caspian sediments, it became necessary to give another explanation of the peculiarities of distribution of the "black earth" than that given by Ruprecht. At the present day the explanation given by Mr. Dokuchaef and his school is regarded as the most probable.

According to him, climatic conditions, as well as the character of the vegetation, imparted to the region of the "black earth" its peculiar contours. The properties of the "black earth," he says, depend on the relative age of the ground, on its subsoil, on the climate, on the relief, and on vegetation. But since vegetation, too, depends on climate, the latter is to be regarded as the main factor in the formation of this soil.

In fact, nothing but the vegetation of the steppes covered by herbaceous plants can form the chernozem. Submerged and marshy ground forms and accumulates organic substances of an entirely different character. Forests are incapable of producing "black earth." Numerous observations show that everywhere under the shade of forests there is formed a gray soil, made up of pieces of the size of a walnut, containing not more than 2 to 3 per cent of organic substances. This soil, having very considerable thickness, was observed everywhere beneath the forests of Russia and Denmark, and a series of special labors were devoted to this subject. Observation even shows that forests taking root on the "black earth" decompose it and gradually transforms it into the gray soil peculiar to forests. Thus it is the condition favorable to the steppe and its vegetation that presents the best combinanion of heat and humidity necessary for the formation of the "black earth." In fact, the numerous excursions and analyses made by Dokuchaef and confirmed by myself in central Asia and Turkestan bear out this idea with striking exactness.

By means of comparison of "black earth" specimens taken in various localities of Russia whose relief and subsoil were analogous, Professor Dokuchaef has prepared a diagrammatic map of the variations in the quantity of organic matter of the "black earth." This map shows that in the eastern parts of the region of the chernozem, in the provinces of Penza, Samara and Simbirsk, we find the soils most rich in organic substances. Toward the northwest from this part of the region spoken of, in proportion as the climate becomes colder and moister the soil becomes less rich in humus, and is gradually transformed into the vegetal earth or sod of the north, or makes room for the soils formed by forests, which begin to dominate beyond the northern boundary of the "black earth." The same thing may be observed toward the southeastern boundary of our region. There, too, the soil becomes poorer in humus, but, according to Dokuchaef, it is the dryness of the climate, unpropitious to the steppe vegetation, that prevents the formation of the chernozem. Dokuchaef's map also gives a series of approximately concentric

bands, the *isohumic* bands, encircling the region richest in humus, where the "black earth" contains as much as 16 per cent of organic substances.

These researches in European Russia attracted the attention of our geologists and botanists, and soon it was learned that in the various parts of Asiatic Russia, where the climatic conditions bear some resemblance to those of chernozem Russia, soils had been found that were analogous if not identical with the "black earth" of Dokuchaef. Thus in the Crimea, in the northern foothills of the Caucasus, in Siberia, and lastly in Turkestan, on the northern slopes of the Thian Shan, "black earth" was found varying in quality according to the climatic law of Dokuchaef. Thus, too, the great Black-Caspian depression is nearly surrounded by a zone of "black earth" varying in breadth and in richness according to the conditions of heat and moisture, and accompanied by a nearly identical vegetation.

The question of the causes of the geographic distribution of the "black earth" being thus solved, did not yet supply an answer to the question, still more interesting from a geologic point of view: the question of the age of the "black earth." Unfortunately there exist but very few observations on this point. The chemical analyses of the "black earth," taken in different parts of Russia, show that the organic substances of the chernozem are accompanied by a number of peculiarities. The quantity of hygroscopic water, of phosphates and of ceoliths, becomes larger in proportion as the relative quantity of humus increases. As these properties are of great agronomic value, the zemstvos (or assemblies) of some Russian governments undertook special investigations of these soils. The zemstvos of Nizhni Novgorod and Poltava prepared maps of their soils, under the supervision of Professor Dokuchaef. The detailed investigations made in those provinces yielded very interesting results, a part of which are summarized in the appended table. They showed that even in the same climate and on the same geologic formations the qualities of the soils may be very different, and that the relief plays an important part in this matter. Thus, for example, Professor Dokuchaef at Poltava, and myself at Kharkof, found the following relations to exist between soil, vegetation and relief:

1. The highest points and those most cut up by crevasses and valleys are richest in forests and in gray soils, and the number of forests increases in proportion to the number of crevasses. On the contrary, the points of gentle, flat relief, sparely provided with deep cuts—in a word, poorly drained—are the region of the "black earth" and of the steppe.

2. The qualities of the "black earth" vary with relative height. The highest points of the steppe are at the same time the richest in humus, although the difference in height is only one to three hundred feet.

3. The regions of the gray soils, especially when they accompany the high banks of streams, are skirted by a zone of intermediate soils formed of the "black earth" half transformed into gray forest soil.

4. The vegetation of the less elevated parts, though composed of species peculiar to the steppe, is less rich in characteristic forms than those of the relatively more elevated parts; while the latter, despite its steppe character, contains several water-loving forms, the former is rich in endemic forms or forms common to it and the Caucasus and its Alpine and sub-Alpine regions.

If we observe the relief of these provinces, we shall see very interesting phenomena. Where the soils are covered by forest they overlie either Cretaceous rocky subsoils or Quaternary clays, drained in all directions by gullies. Quite a different aspect is presented by the level lands covered by the "black earth." There the ground is

often covered by marshes and by little lakes, sometimes round and very shallow. The number of these marshes and lakes was formerly very great, but they have disappeared before the eyes of the inhabitants. The brooks on these plateaus have banks that are but little pronounced, and on following their courses you come upon the steppe, where you can hardly trace the beginning of the brook. Beneath the soil are found loessoid clays difficultly pervious to water.

What is true of these two governments, which are now well described, is true of the whole surface of chernozem Russia. Nowhere does the "black earth" prevail alone; everywhere it is interrupted by islets of sand or of gray earth with forest, and everywhere the size and number of forests depend on the character of the relief; and wherever the loess prevails, there we see the steppe, the steppe marshes and the "black earth." All this shows that the climate of this part of Russia is as favorable to forest vegetation, which is detrimental to the "black earth," as to the steppe, and that there are in the soil itself certain conditions which now are more favorable to the forest, now to the prairie. The steppe, despite the dryness which characterizes it, seems to be less well drained than the spots where the forests prevail; the latter seem to augment in number in proportion as the relief is rendered less regular owing to the growth of the gullies, the number of which increases with exceeding rapidity with the cultivation of the soil.

If these observations are confirmed in other provinces of Russia, we shall have to suppose that we are witnessing an enormous phenomenon of drainage of southern Russia, where the steppe and the formation of the "black earth" play a part intermediate between the marshy, semi-lacustrine state of the postglacial epoch and the forest epoch. Drained by the great rivers, the clayey and loessoid subsoils, impervious to atmospheric water, in a climate of scanty rain, must have been covered by a vegetation of herbs of semi-Alpine origin, which covered the highest points during the preceding epoch. As the forest enters through the moister gullies into the center of the "black earth" plateaus it transforms by its roots the soil, little permeable to water, into gray earth, which, acting as a reservoir of atmospheric water, allows the forest vegetation to occupy the surface of the steppe. In other words, we see here what was witnessed, according to Nathorst's theory, in Europe at a more remote period, when the tundras of the postglacial epoch gave place to steppes with antelopes, which in their turn were covered by forests during the historic epoch.

But, in order to be sure that this view is correct, we still need observations on the postglacial deposits of Russia, those loessoid strata, poor in fossils, so widely spread over the surface of southern Russia, on the appearance of which the features of the morainic landscape peculiar to northern Russia disappear. Yet before these researches, which already occupy much attention, are completed, I desire to call your attention to the analogy existing between the soil and the character of our steppes and the American prairies. So far as it was possible to me to study the American literature on the subject, which unfortunately is but scantily represented in our provincial universities, I was struck by the resemblance existing between the Russian "black earth" and that of the prairies of Minnesota and Illinois. It may suffice, in order to see this resemblance, to compare my list of Russian analyses with the American analyses. There is close correspondence between the climates of the two countries as regards temperature and rainfall. Moreover, the history of the evolution of the prairie, as traced by Lesquereux (who thinks that the prairies are even now in the state of transformation from the stage of inundated, lacustrine

and marshy land to the stage of the steppe), the relations existing between relief and soil and the vegetation of the prairies described by Engelmann, Whitney and Winchell (who draw a picture, exceedingly like that seen in Russia, of regions with loessoid soil, covered by prairie, with elevated spots, stony and drained and covered by forest, whose domain becomes larger despite human culture), the influence of the climate analogous to the climate of the Russian steppes, the value of which had been formulated by Professor Dana—all this reminded me very forcibly of what I had seen in my country. Moreover, the whole history of the continent, from the Paleozoic downward, permits the drawing of analogies between the great valley of the Mississippi on the one hand and the Euxine-Caspian-Siberian valley on the other—these youngest parts of the two continents situated between the Paleozoic regions and the mountains of more recent origin; both were reservoirs of the glaciers of the glacial epoch, and both had their epoch of inundation.

In closing this essay I take the liberty of making a special appeal to those American geologists who are interested in the Quaternary geology of their country If it is possible to establish closer relations between Russia and America, the question of the origin of the American prairies and of the Russian steppes will be easier to solve. If it is possible on the one hand to find in America relations between soil, climate, relief, and vegetation analogous to those of Russia, as well as a dependence on climate analogous to ours; if the distribution of the "black earth" around the valley of the Mississippi shows the same peculiarities as that around the Euxine-Caspian depression; finally, if the hypothesis of Professor Lesquereux is confirmed by more numerous proofs in Russia and in America, I hope the question of the age of the "black earth" will be solved, and it may be decided more positively whether most of the American prairies are merely a less advanced stage of evolution than those of Russia. Allow me, then, to repeat the wish that the geologists of these two countries may work together and in harmony for the solution of this question, the interest and practical value of which are beyond doubt.

The detailed results of Professor Dokuchayef's observations on the "black earths" of Russia are summarized in the following table, which is extracted from his work on the Russian chernozem, pp. 353–372:

Thickness and Contents in Humus and hygroscopic Water of the different Soils of Russia.

LEFT SHORES OF THE VOLGA AND THE KAMA.

No.	Locality.		Thickness (in feet).	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
1	57° 06′	47° 30′	6′ 8″	1.703%	5.724%
2	55 42	50 12	2 4	11.313	7.906
3	55 36	50 48	1 0	7.788	5.044
4	55 24	50 00	2 2	10.845	9.624
5	55 18	53 30	....	12.502	7.011
6	55 18	53 30	....	14.218	8.296
7	55 18	48 42	2 6	11.728	8.375
8	55 12	50 00	1 3	13.0±	8.142
9	55 06	50 00	2 0	7.360	....
10	55 00	47 00	1 11	5.432	3.273

Left Shores of the Volga and the Kama—Continued.

No.	Locality.		Thickness.	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
11	54° 24′	51° 30′	1′ 7″	15.423%	10.597%
12	54 18	46 00	3 11	4.838	2.268
13	53 54	50 00	2 0	12.355	10.245
14	53 48	46 42	2 4	3.370	1.831
15	53 42	50 00	2 4	13.070	5.405
16	53 30	52 00	2 2	9.785	9.566
17	53 24	48 30	2 4	7.616	4.230
18	53 12	47 48	2 1	10.494	5.178
19	53 06	50 00	0 8½	1.727	1.290
20	53 06	49 18	2 6	5.018	3.225
21	53 00	50 00	2 0	6.662	3.234
22	53 00	47 18	2 6	10.480	5.650
23	52 48	53 30	2 4	15.013	5.033
24	52 48	53 42	2 4	14.551	4.707
25	52 42	49 54	2 9	3.458	3.854
26	52 42	49 54	2 6	2.762	1.800
27	52 30	53 30	2 0	11.933	5.322
28	52 30	45 48	2 4	5.293	. . . .
29	52 24	50 48	2 3	6.701	4.485
30	52 24	49 42	0 8	3.815	2.842
31	52 24	49 42	2 0	11.582	9.504
32	52 24	47 48	1 6	6.915	3.105
33	52 18	47 36	1 2	6.662	5.144
34	52 12	53 36	1 4	6.073	3.234
35	52 12	47 36	2 0	10.378	5.440
36	52 06	51 12	1 6	10.033	4.557
37	52 00	46 24	1 3	6.445	. . . .
38	51 48	52 48	1 11	2.432	2.721
39	51 30	46 36	1 1	4.193	. . . .
40	51 30	44 00	0 7	1.922	2.178
41	51 18	44 42	0 9	4.218	2.320
42	51 12	46 18	1 11	5.325	. . . .
43	51 12	44 48	1 5	9.105	3.526
44	50 54	46 54	2 0	4.799	. . . .
45	50 54	46 54	0 6	2.769	(?)
46	50 54	45 18	1 3	3.621	4.265
47	50 30	46 48	0 5½	3.030	(?)

Tract between the Volga and the Dnieper.

No.	Locality.		Thickness.	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
48	55° 30′	46° 36′	0′ 7″	4.677%	(?)
49	55 24	46 30	1 6	6.787	4.549%
50	55 18	46 30	0 8	3.651	2.397
51	55 12	46 00	2 3	9.543	(?)
52	55 00	46 18	1 6	9.200	3.940

TRACT BETWEEN THE VOLGA AND THE DNIEPER—Continued.

No.	Locality.		Thickness.	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
53	. . . .	. . . .	1′ 2″	12.988%	6.829%
54	54° 18′	46° 00′	2 6	19.171	(?)
55	53 54	46 30	2 3	7.704	4.912
56	53 12	46 06	2 2	4.523	(?)
57	(?)	(?)	. . . .	7.400	2.990
58	52 30	45 48	1 4	15.079	(?)
59	52 00	45 00	1 6	9.647	5.211
60	51 30	44 00	2 0	10.544	4.425
61	51 30	44 00	. . . .	12.040	4.966
62	50 06	43 06	1 9	2.072	3.129
63	50 00	42 48	1 3	5.429	6.601
64	49 36	42 54	1 2	1.450	0.927
65	49 18	42 36	1 0	1.422	0.933
66	48 48	42 06	0 11	2.526	5.127
67	48 42	42 12	0 9½	0.908	1.081
68	48 06	43 42	0 4	1.081	1.135
69	55 54	42 36	1 1	3.495	2.158
70	55 48	42 00	1 5	4.010	2.530
71	55 24	42 30	0 7	7.710	3.490
72	55 24	42 24	1 11	11.000	5.060
73	55 18	42 24	2 6	10.080	4.500
74	55 18	42 24	1 0	4.210	1.530
75	56 00	42 48	0 6½	1.140	(?)
76	55 54	42 48	1 4	4.653	1.580
77	55 54	42 48	1 3	6.138	2.260
78	55 48	42 54	1 5	5.520	2.950
79	55 42	42 00	1 0	2.265	0.667
80	55 36	43 00	0 8	5.910	2.290
81	55 24	42 00	1 9	7.100	3.400
82	55 30	43 06	2 2	10.400	(?)
83	55 24	42 48	2 6	7.170	4.000
84	55 24	43 00	2 10	9.877	3.871
85	55 18	43 06	2 7	14.767	5.400
86	55 12	43 06	2 8	13.565	4.170
87	55 00	43 00	1 8	8.095	3.041
88	55 00	43 00	1 6	11.554	3.801
89	56 06	42 18	0 6	0.910	0.860
90	56 00	42 48	0 8	3.410	2.040
91	55 54	42 18	1 1	7.540	2.448
92	55 54	. . . .	1 4	7.880	(?)
93	55 48	42 24	1 6	5.850	(?)
94	55 42	42 30	0 9	3.910	2.410
95	55 36	42 12	2 4	6.320	2.530
96	55 36	42 12	2 6	5.040	3.310
97	55 36	42 30	1 10	8.420	3.580
98	55 30	42 48	1 11	5.000	2.194
99	55 00	42 54	2 1	4.170	1.930
100	54 54	42 48	0 11	2.680	1.940
101	54 48	. . . .	0 8	4.060	(?)
102	54 42	. . . .	0 4	2.500	0.440
103	54 36	. . . .	2 0	7.200	3.860
104	54 30	42 54	3 0	9.410	5.017
105	54 24	42 54	2 1	9.970	4.960

TRACT BETWEEN THE VOLGA AND THE DNIEPER—Continued.

No.	Locality.		Thickness.	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
106	56° 00′	42° 00′	0′ 5″	1.700%	0.920%
107	55 54	42 18	1 0	3.770	1.070
108	55 36	42 06	0 9	3.050	1.770
109	55 24	42 12	1 2	3.784	1.835
110	55 00	42 18	1 6	7.110	2.940
111	55 00	42 18	1 2	6.900	(?)
112	54 54	42 24	1 1	5.490	3.490
113	54 48	42 24	2 0	4.900	2.970
114	....	42 30	1 8	6.086	(?)
115	54 24	42 36	2 8	9.630	4.100
116	54 24	42 36	3 0	16.110	6.050
117	54 12	42 48	2 1	10.376	4.477
118	54 12	43 00	....	10.056	3.501
119	54 18	44 18	0 11	7.576	4.156
120	51 48	42 24	1 6	6.158	4.346
121	51 36	43 36	1 8	8.276	4.729
122	51 18	42 30	....	9.561	5.840
123	55 36	39 42	0 4½	0.590	0.072
124	57 12	37 00	....	8.5±	(?)
125	56 30	37 30	0 11	5.166	....
126	56 06	38 00	0 9	1.035	1.751
127	55 24	41 00	1 8	4.572	2.901
128	55 18	40 42	0 8	0.757	0.047
129	55 30	41 30	0 9	3.980	3.146
130	55 24	41 36	1 9	5.642	2.851
131	....	....	0 4½	1.436	....
132	....	....	1 10	8.831	....
133	55 48	32 00	0 5½	1.150	1.123
134	55 48	32 00	0 6½	2.338	2.083
135	55 48	32 00	1 2	3.368	2.013
136	55 48	32 00	1 3	9.796	6.093
137	55 06	36 30	0 8	2.108	2.489
138	54 42	36 36	0 9	2.503	1.850
139	54 36	36 30	0 10	3.297	2.981
140	54 30	....	1 6	6.782	3.732
141	54 18	36 00	1 4	6.205	4.116
142	54 18	37 12	1 2	2.655	3.734
143	53 42	37 24	1 4	5.999	7.988
144	53 30	39 30	3 4	7.625	11.093
145	52 30	39 18	3 7	9.595	6.452
146	52 18	42 00	3 10	13.703	7.006
147	52 18	42 00	3 8	11.616	13.470
148	51 30	39 30	2 5	9.148	6.363
149	50 30	40 24	2 3	6.667	3.663
150	54 30	33 24	1 2	2.527	1.031
151	54 24	33 06	0 10	1.684	1.457
152	54 00	34 00	0 10	2.338	2.080
153	54 18	35 18	1 2	2.542	4.828
154	53 42	35 00	2 0	8.747	8.062
155	53 30	34 36	2 6	8.109	9.126
156	53 24	34 24	0 8	4.959	4.970
157	53 21	34 42	1 6	8.729	3.537
158	53 18	33 42	1 5	4.599	2.154

TRACT BETWEEN THE VOLGA AND THE DNIEPER—Continued.

No.	Locality.		Thickness.	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
159	53° 24′	33° 42′	1′ 7″	5.265%	6.552%
160	53 00	33 48	1 2	4.176	5.153
161	53 00	33 12	1 1	3.370	1.660
162	53 00	33 42	1 2	4.750	3.509
163	53 00	34 00	2 2	5.825	7.282
164	53 00	34 00	2 5	8.115	4.096
165	52 48	35 00	1 11	8.523	6.400
166	52 24	35 24	2 0	8.060	3.620
167	52 18	34 00	2 2	6.106	7.698
168	51 54	35 00	2 3	4.607	2.176
169	51 48	34 54	2 0	3.812	5.635
170	51 45	34 36	2 0	7.301	4.000
171	51 36	33 48	1 3	4.268	2.747
172	51 36	33 48	2 3	4.811	4.452
173	51 36	33 48	1 6	3.300	1.810
174	51 30	34 42	2 11	4.365	3.186
175	51 43	37 00	3 1	11.427	13.734
176	51 12	34 24	2 6	7.319	4.809
177	51 12	34 24	2 10	6.031	4.966
178	(?)	(?)	(?)	7.959	5.002
179	50 00	37 00	2 11	4.451	5.980
180	48 00	37 00	2 2	5.647	6.798
181	47 31	38 00	1 8	7.0±	10.610
182	53 00	33 12	(?)	3.655	1.770
183	52 18	29 54	1 0	1.556	1.713
184	52 00	31 00	0 10	2.765	1.620
185	51 48	31 12	1 4	1.425	1.188
186	51 36	31 36	(?)	1.680	1.204
187	51 24	31 36	2 11	1.862	1.237
188	51 18	31 30	2 11	3.522	3.612
189	51 36	33 00	....	3.010	....
190	51 27	32 36	1 4	2.069	2.554
191	51 18	30 54	4 8	2.514	2.645
192	51 15	30 30	3 3	2.800	1.240
193	51 06	29 30	3 6	3.608	2.647
194	51 06	29 30	....	2.345	2.395
195	50 42	31 18	2 6	5.450	3.963
196	50 30	31 48	4 0	3.830	2.830
197	50 24	31 18	2 6	3.495	2.797
198	50 18	32 00	2 6	3.024	....
199	50 12	32 42	3 0	3.240	3.791
200	50 00	30 12	3 5	4.579	5.431
201	50 00	30 42	2 0	3.401	2.653
202	49 30	32 00	1 10	2.865	2.404
203	49 18	31 30	3 0	3.730	2.170
204	50 36	34 18	....	4.141	3.810
205	50 39	34 18	1 6	6.047	4.040
206	50 39	34 18	1 11	4.231	5.510
207	50 42	34 12	2 0	5.460	2.350
208	50 30	33 42	2 3	3.864	2.207
209	50 30	33 24	2 6	7.585	2.550
210	50 18	33 24	3 0	6.591	3.809
211	50 12	33 00	3 2	6.425	4.467

TRACT BETWEEN THE VOLGA AND THE DNIEPER—Continued.

No.	Locality.		Thickness.	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
212	50° 18′	32° 18′	2′ 9″	5.709 %	3.280 %
213	50 00	33 54	3 2	8.786	6.880
214	49 00	34 00	3 0	8.519	10.254
215	48 30	33 12	2 6	3.892	2.059

TRACT BETWEEN THE DNIEPER AND THE DNIESTER.

No.	Locality.		Thickness.	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
216	50° 24′	28° 12′	0′ 9″	0.964 %	1.615 %
217	50 24	28 00	. . . .	1.298	0.701
218	50 12	27 48	2 7	2.512	2.800
219	50 06	27 36	1 8	2.883	1.830
220	49 36	26 36	2 3	3.116	2.378
221	49 24	26 24	2 6	5.167	4.562
222	50 06	25 06	0 6½	2.695	1.138
223	50 36	23 08	0 9	2.855	2.050
224	49 24	24 36	. . . .	3.368	2.753
225	49 48	27 48	2 11	3.514	1.901
226	49 30	29 00	2 11	4.372	2.209
227	49 12	29 18	4 2	2.336	1.501
228	49 12	29 18	3 11	2.809	1.632
229	48 42	27 30	3 10	5.962	4.078
230	48 36	27 42	4 6	5.035	3.116
231	48 24	28 12	2 6	3.887	3.409
232	48 18	28 18	2 11	6.102	5.285
233	47 48	28 00	3 7	5.980	3.820
234	49 00	25 36	2 0	2.822	2.800
335	48 15	26 00	2 5	3.729	3.087
236	48 00	26 12	3 0	5.718	3.267
237	. . . .	26 00	1 2	9.230	4.580
238	48 30	30 00	4 8	4.912	2.457
239	48 42	30 18	2 9	5.816	3.273
240	48 42	30 18	. . . .	1.870	1.533
241	48 42	30 42	2 6	3.670	1.805
242	49 00	31 06	2 11	2.677	3.594
243	48 06	26 36	3 0	3.457	4.914
244	48 00	28 30	3 4	5.437	4.253
245	47 42	30 18	(?)	5.756	4.646
246	47 24	30 12	(?)	6.274	4.463
247	47 12	30 00	(?)	3.222	3.300
248	48 30	32 51	3 0	3.215	5.126
249	47 54	27 12	2 8	12.247	7.930
250	46 54	27 42	2 6	7.196	7.393
251	47 00	32 00	1 8	1.999	3.876

NORTHERN COAST OF THE BLACK, SIVASH AND AZOF SEAS AND THE BANKS OF THE DON.

No.	Locality.		Thickness.	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
252	46° 48′	27° 48′	2′ 0″	5.074%	6.941%
253	46 36	28 00	1 9	3.559	3.479
254	47 00	29 42	1 4	4.921	4.463
255	46 24	30 18	1 8	2.224	3.738
256	46 12	32 24	2 2	6.025	4.178
257	46 12	32 30	2 3	4.844	8.370
258	46 48	33 00	2 5	2.368	4.130
259	46 42	34 30	2 4	5.180	10.845
260	47 06	35 18	(?)	5.760	4.690
261	47 18	35 30	1 2	5.375	5.283
262	47 24	36 36	2 3	4.947	8.803
263	47 12	36 24	2 2	4.437	8.551
264	47 30	37 48	2 1	5.320	4.408
265	46 36	48 42	0 11	4.701	5.930
266	47 43	39 54	0 9	1.969	3.424
267	48 49	41 06	1 3	2.932	2.507

CAUCASUS. LAND OF THE KUBAN ARMY, AND CRIMEA.

No.	Locality.		Thickness.	Humus.	Hygroscopic water.
	Latitude.	Longitude.			
268	43° 00′	44° 42′	0′ 4½″	4.041%	3.495%
269	43 24	44 18	1 2	4.337	2.962
270	43 18	44 00	1 9	7.061	2.168
271	43 18	43 00	1 8	4.768	4.406
272	43 18	42 42	1 0	4.777	2.348
273	43 00	42 18	2 1	9.266	3.543
274	43 42	41 42	0 11	5.586	2.657
275	44 12	41 00	1 3	7.830	4.727
276	44 42	39 30	1 5	7.436	4.546
277	45 30	38 18	1 11	4.294	1.952
278	46 30	37 18	1 6	5.431	4.060
279	45 24	38 00	1 6	5.116	3.284
280	45 18	37 36	2 0	4.629	4.391
281	45 00	37 09	1 11	4.912	2.322
282	45 00	36 36	2 8	4.934	4.443
283	45 12	36 12	2 1	5.707	4.464
284	45 18	35 48	1 6	5.086	4.049
285	46 00	32 30	0 3½	2.0+	1.330
286	45 30	32 00	1 0	3.261	2.983
287	45 06	33 00	(?)	4.418	6.370
288	45 06	33 00	....	5.211	3.820
289	44 54	31 54	(?)	3.768	6.653
290	44 54	31 54	(?)	4.137	5.472
291	44 24	31 48	0 8	8.543	4.781

In discussing the paper, Professor E. W. Hilgard spoke as follows:

I have been greatly interested in Professor Krassnof's paper, as I have studied the American "black-prairie soils" in considerable detail; and, on the whole, I agree entirely with him in his conclusions as to the conditions under which such soils may be formed. There is one conclusion, however, which he has only casually mentioned, yet which is, according to my investigations, a *conditio sine qua non*. I refer to the neutrality of the "black earths" as compared with the decided acidity of peaty soils. The cause of this neutrality is the presence of at least a certain minimum amount of calcic carbonate; and in its absence I think such soils cannot be formed. The fact mentioned by him, that the chernozem occurs in the main in the loess region only, assures me that the same condition is fulfilled in Russia. All the "black-prairie" soils I have studied in this country are essentially calcareous soils, usually overlying limestones or marly rocks, or, in the case of drift areas, calcareous gravels. The eminent usefulness of lime in soils is well understood, and those in which it and the abundant products of organic decomposition are combined might naturally be expected to be profusely fertile; and this is notoriously true of our prairie soils, as well as of the Russian "black earth"—it is as true in California, where such soils are now in process of formation, as it is of the prairies of the west.

I have heretofore inferred the calcareous nature of the chernozem from analyses communicated to me by Professor Grandeau; I am pleased to have the fact confirmed by Professor Krassnof. I do not, however, wish to be understood as asserting that calcic carbonate alone can produce such soils without other concurrent conditions, such as were mentioned in the paper, nor that such soils must necessarily be effervescent with acids. All the essential effects of lime in soils are assured by the presence of one or two per cent of the carbonate, or even less; which amounts, when finely diffused, will not usually show effervescence with any degree of certainty, but suffice to produce characteristic lime vegetation, and to guide the field geologist in the outlining of calcareous areas.

I cannot but express also my gratification at having these latest of geological formations—the soils—introduced into the discussions of this Society. Their economic importance certainly justifies it, but thus far their consideration has usually been relegated to the chemical or agricultural societies alone.

Professor G. C. Broadhead said:

Never having had the pleasure of visiting southern Russia, I cannot, of course, say anything of the region spoken of in so interesting a manner by Professor Krassnof; but some time ago I was interested in the "black earth" of those steppes described in a volume of Rèclus. I was forcibly struck with the resemblance to our own "black-prairie soils." Now, I do not say that in certain regions these soils cannot be found, but my own observation goes to show that there are well-marked and extensive areas of such in the states of Illinois, Missouri and Kansas. In Illinois the "black soil" covers the greater part of the counties of Moultrie, Macon and Piatt, resting on either the drift or else the upper Coal Measures. In Missouri the "black soil" is found in Saline county, resting on beds of the lower Coal Measures. Further westward in Missouri, in the counties of Cass and Jackson, it rests upon the rocks of the upper Coal Measures. It is also well developed in northwestern Missouri, where it lies upon the drift or else directly on rocks of

the upper Coal Measures. Westwardly, in Kansas, the "black soils" rest upon the rocks of the upper Coal Measures. Limestones generally prevail in these regions, being rather scarce, however, in the part of Illinois above named, as well as in Saline county, Missouri. I have been disposed to ascribe the origin of these soils in a large measure to disintegration of calcareous beds. The areas in which these soils prevail are also chiefly confined to the prairie regions and not to those areas where trees seem to have always existed. They seem peculiar to treeless regions, but may extend a little way into the adjoining woodland.

Remarks were made also by A. S. Tiffany, T. C. Chamberlin, Robert Hay, and the author.

The following paper was read in the French language, and afterward a résumé was given in English by Professor Stefan Sihleano:

ON THE EXISTENCE OF THE *DINOTHERIUM* IN ROUMANIA.

BY PROFESSOR GRÉGOIRE STEFANESCU, OF THE UNIVERSITY OF BUCHAREST, ROUMANIA.

I take the liberty of claiming, for some moments, your attention on a question in which most of you will be interested, as it occurs for the first time in our science: namely, the existence of the *Dinotherium* in Roumania.

Some years ago the geology of Roumania was almost entirely unknown—I say almost, because, although we had some vague notions and brief descriptions of certain isolated regions, theories were generally founded on deductions drawn from the geological structure of the neighboring countries, or upon superficial notes given by foreign travelers who had more or less rapidly run through Roumania.

The geology of this country figures also in Dumont's geological map of Europe, but neither the enumeration of the geological systems nor their respective limits are generally accordant with facts, as we can easily understand, since all Dumont's materials had no other origin than that which I spoke of above. We have now, by the work of some Roumanian geologists, and especially after the studies made by the Roumanian geological survey, more complete and exact knowledge of the geology of that country.

But it is not my intention to occupy you with the geological systems and with their extension into Roumania. You will be able to form an idea of them by throwing a glance on the twenty-four sheets of the geological map of Roumania published by our geological survey, which contain about the half of all the country, and which I have sent to the secretary of the Geological Society of America. You may examine also the small geological map of the whole of Roumania that I published last year, and which I now have the honor to present to the members of this learned body. As you may see, the Tertiary and Quaternary systems are much developed and extended in Roumania, and many fossil remains of the larger mammalia have been found there, viz., rhinoceros, mastodon, deer, gazelle, antelope, ox, elephant (especially *Elephas meridionalis*, *E. antiquus* and *E. primigenius*), camel and, lately, the *Dinotherium*.

I received in 1878 a fossil molar tooth found at Gaiceana, in the judet (district) of Tecuciu. It was the last but one molar of a *Dinotherium*, but it was so large that

it could not have belonged to the usual *D. giganteum*, as you may judge from the following dimensions:

Antero-posterior diameter	meters	0.12
Transverse "	"	0.12
Height of the crown	"	0.08
Height of the root	"	0.14
Distance between the hills of the crown	"	0.05
Thickness of the hills at their basis	"	0.05

These uncommon dimensions should lead us to look at these remains as belonging to another species than the usual *D. giganteum*, which may be named *D. gigantissimum*.

I went then immediately to Gaiceana for the purpose of studying the bed yielding the remains. It consists of a micaceous yellowish-gray sand, with small sheets and concretions of sandstone of different sizes. This sandstone must have been formed from calcareo-siliceous infiltrations evidently posterior to the imbedding of the *Dinotherium* remains, as the tooth was deeply impressed in one of the concretions, which had to be broken in order to take the molar away, and in which it left a beautiful impression. The dip of the strata is low, and the strike is northwest-southeast; they belong to the middle Miocene. I found there other and smaller molars, a part of the lower jaw, and the incurved symphyses, with small incisors

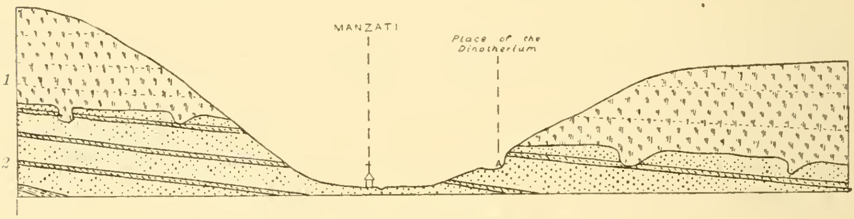


FIGURE 24—*Section through Manzati Valley.*

1 = Loess; 2 = Mocene beds.

Twelve years later (in 1890) I became aware that at another point, *i. e.*, Manzati, in the judet of Tutova, in a bluff which had been eroded by the rains, many bones of a huge animal had been uncovered. I went there immediately, and found that several persons had already taken parts of the head of a *Dinotherium*. The first excavation which I made uncovered a portion of a jaw with two molars; but as it was winter and the weather was very inclement, I postponed the investigation until spring.

The fragments which I found on this occasion are very important, viz:

1. The right branch of the lower jaw, with its five molars. This is almost complete; only the symphysis and the ascending branch are deficient, and nevertheless the length reaches 0.80m., its height at the second premolar is 0.30m., and it is 0.16m. thick.

2. A portion of the left branch of the lower jaw, with the two posterior molars.

3. A fragment of the right branch of the upper jaw, with a portion of the palatal bone and three molars.

I went again to Manzati in the month of May and found other remains, viz:

1. Ten ribs, almost complete, one of which was no less than 1.20m. in length.
2. An omoplat, which could not be taken away except in pieces, but which I measured *in situ*. Its transverse diameter was 1.15m.; it was 1.05m. from the glenoidal depression to the posterior ridge; the diameter of the glenoidal depression alone is 0.25m.

The deposit yielding the bones stands on the right bank of a small valley near the village of Manzati. The geological structure of this valley, running from north to south, is as follows: In the lower part we find a succession of strata of more or less fine micaceous sand, sometimes yellowish, elsewhere grayish, which alternate with sandstone strata disposed in small sheets or concretions, dipping gently eastward. Upon these strata, which belong to the middle Miocene, lies unconformably a heavy stratum, 25 to 30 meters thick, of a yellow or grayish loess, sometimes sandy and more rarely containing clay. In the upper part of the Miocene strata many cavities have been produced by erosion, which have been afterwards filled by the earliest strata of loess, containing small concretions of white marl and many fragments of worn sandstone.

We now have, therefore, two regions in Roumania in which remains of *Dinotherium* have been found, Gaiceana and Manzati, and which must be added to the other points on our globe in which geologists have found remains of this giant of the Tertiary world.

Professor E. D. Cope spoke upon the subject of the paper, reviewing the character and distribution of *Dinotherium;* following which a recess was taken until 2 o'clock p. m.

Afternoon Session, Tuesday, August 25.

The Society reconvened at 2 o'clock p. m., meeting in two sections. The papers relating to the Pleistocene were read in the second section, meeting elsewhere in Columbian University, the proceedings of which appear on a later page.

The first paper read in the main section was—

THE ELÆOLITE-SYENITE OF BEEMERVILLE, NEW JERSEY.

BY JAMES F. KEMP.

[*Abstract.*]

The paper opens with a brief description of the other American areas of elæolite-syenite (Montreal, Canada; Litchfield, Maine; Salem and Marblehead, Massachusetts; Magnet Cove, Arkansas) and gives a synopsis of the work which has been done upon them. Reasons for suspecting the existence of an outcrop in the Adirondacks are stated. An outline is then given of the discovery of the Beemer-

ville exposure and of the previous description by Professor B. K. Emerson. It is shown that only the northern third of a dike three miles long had been treated. Reference is also made to the associated basic rocks, already described by the author, and they are stated to be identical with some peculiar dikes of which an account by the author will appear in a forthcoming report of the Arkansas geologic survey, where they are called ouachitite.

The extent and geologic relations of the Beemerville syenite are next taken up in detail. The syenite comes out as a great dike three miles in length, running northeastward on the contact between the Kittatiny (Oneida) conglomerate and the Hudson River (Trenton) slates. It is 300 to 400 yards wide. The dike was followed from the northern to the southern end; the rocks collected are described from thin sections and chemical analyses. As principal results, it is shown that normal elæolite-syenite forms the northern third and the southern extremity; that most excellent elæolite-porphyry occurs in the middle third; and that toward the southern extremity the dike becomes much more basic, running down to about 41 to 42 per cent SiO_2, and showing marked affinities with theralite. The normal elæolite-syenite contains orthoclase, elæolite, cancrinite, sodalite, aegirine, reddish-brown biotite, titanite, magnetite and pyrite. Fluorite has been detected by Professor Rosenbusch in some specimens sent him, although overlooked by the writer. Careful search failed to discover either eudialyte or eucolite. The elæolite-porphyry contains crystals of elæolite up to an inch in diameter. Almost at the same time with its discovery, this type of rock was also found in Arkansas by the late J. Francis Williams, with whom the writer was in active correspondence; and these two are the first announcements of this rare species in the United States. The rock resembles the Brazilian tinguaites, and has additional mineralogical peculiarities to those mentioned above. The very basic rock of the south is worthy of comment, and the remarkable absence of plagioclase from a rock so low in silica may be emphasized.

A discussion of the associated basic rocks (ouachitites) follows, and some interesting facts are brought out as to their relations with similar rocks elsewhere in the world. Some new dikes are also recorded. The paper closes with a short description of the contact metamorphism. Acknowledgments are due to Dr. J. Francis Williams, of Cornell University (recently deceased), and to Professor H. Rosenbusch for valuable aid.

In the subsequent discussion J. Francis Williams announced that W. S. Bayley, of Colby University, had discovered elæolite in the hornblende-syenite of Hawes from New Hampshire; and J. E. Wolff stated that he had learned of basic rocks occurring in close association with the Salem, Massachusetts, elæolite-syenite. Further remarks were made by G. H. Williams, on the general subject of the paper, and by J. E. Wolff on related rocks recently examined by him in the Crazy mountains of Montana.

The next paper was—

NOTES ON THE TEXAS-NEW MEXICAN REGION.

BY ROBERT T. HILL.

Contents.

Introductory.

The present paper is intended to call attention to certain widely distributed features of the western Texan and eastern New Mexican region not hitherto described. The region treated embraces the country west of the longitude and south of the latitude of the Ouachita mountains (approximately corresponding with the thirty-fourth parallel). The features discussed are mostly non-mountainous, and of later age (Neocene) than the latest mountain uplifts.

I have previously shown that the salient topographic features of the region consist of:

1. A series of modern and ancient coast and dip plains,* comprising strata extending from the Comanche to recent in age, which cover the eastern half of the state, and collectively forming what may be called the coastward incline. This embraces the coast prairies (Pleistocene), the Washington prairies (Neocene), the Eolignitic or forest region (Eocene), the main black prairie (upper Cretaceous), the Grand prairie (Comanche or lower Cretaceous), and the two Cross-Timbers (bases of the upper and lower Cretaceous respectively). The Llano Estacado may be in some respects classified with the coastward incline, but for the present it may be treated separately.

2. The central denuded region, including the denuded area now occupied by the great rock sheets of the Paleozoic and early Mesozoic (Red beds) of central Texas, mostly dipping westward, which lie unconformably beneath the group of the coastward incline and the Llano Estacado, and are exposed by their removal through erosion.

*Professor W. M. Davis has objected to the use of this term (Bull. Geol. Soc. Am., vol. 2, 1890, p. 575) and substitutes the term "structure plain." Inasmuch as there may be many kinds of structure plains, of which a dip plain is a specific kind, I continue the use of the term dip plain in preference to the generic one proposed by him.

3. The two great mountain systems which limit the region—the Ouachita on the north, and the Rockies and the basin ranges of the trans-Pecos region and northern Mexico on the west; the first of which (the Ouachita system of Arkansas and Indian territory) is older than the plains of the coastward incline system against which they were laid down. The second system is composed of the basin mountains, which consist in part of the uplifted, folded and crumpled southern rock sheets of the earlier of these plains, *i. e.*, those founded on rocks of Cretaceous age.

4. Plains laid down against and of later age than the mountain folds and synchronous in age with the later formations of the coastal series, including the Llano Estacado, and the lacustral or basin sheets laid down between the mountains and in the erosion valleys of the plains.

The Raton-Las Vegas Plateau.

It is the popular conception, founded upon the conditions about Denver and elsewhere, that the structure of the plains of Tertiary and later origin is such as to abut everywhere against and incline away from the mountains toward the present coast and Mississippi valley, forming a suitable condition for the transmission of underground waters derived from the mountains. This conception is a mistaken one, so far as northern New Mexico is concerned; for south of the Colorado line the western margin of the plains recedes away from the mountains eastward, and interposed between the Llano Estacado proper and the Rocky mountains there is an interesting topographic feature—the remnant of an older plane or Eocene land area, the structure of which dips toward the mountain front.

For this great region of country in northern New Mexico, lying east of the true Rocky mountains and east of the Llano Estacado, south of the Purgatoire and north of the Gallinas, the name of the Raton-Las Vegas plateau may be used to give distinction from the true Rocky mountains toward the west and the Llano Estacado toward the east. This district embraces the buttes and mesas known as the Raton mountains, the Mesa de Maya, and many other remnants of a former plain, and in addition the subsequent plains of erosion upon which the eminences stand and upon which the Santa Fé railway is built from Trinidad to the Pecos. The cities of Trinidad, Folsom and Las Vegas may be considered as bench-marks along the northern, eastern and western boundaries respectively of this region, while Raton, Springer, Maxwell and other points along the Santa Fé railway between the Purgatoire, at Trinidad, and the Pecos are located upon it. Its southern boundary is the superb escarpment of the Canadian-Pecos valley, which runs eastward from the Pecos, east of Pecos, crossing near by to the Texas line. This escarpment, as shown on the topographic map (Corazon sheet) of the United States Geological Survey, is over 1,200 feet above the Canadian valley, which it overlooks.

In traveling eastward from the foothills of the Rocky mountains at Las Vegas hot springs (altitude, 7,000 feet) the profile of the Raton plateau east of Las Vegas ascends for 13 miles to the breaks of the Canyon del Agua, where the escarpment of Dakota sandstone of the Canadian-Pecos valley is reached. This is an almost vertical descent of 1,200 feet to the ranch at its base, where the Red beds begin. This precipitous wall extends irregularly eastward for 100 miles, forming the northern wall for the Canadian-Pecos valley, in the lowest portions of which the streams of the Canadian and Pecos flow over 1,500 feet below the summit of the plateau. This valley-plain is irregular in outline and of enormous area. In it the mountain drainage of the Pecos and Canadian first approach each other and then separate upon

their long and different journeys to the sea, around the salients of the northwestern escarpment of the Llano Estacado, which looms up in the distance like a majestic wall. Language cannot describe the magnificence of the scenery here. Everywhere is seen the grand results of profound erosion, by which the overlapping formations (Dakota, Denison and Trinity beds) have been stripped from the horizontal Red beds, which constitute the valley floor, and has left standing in the valley numerous remnants of the plain in the shape of great circular buttes and mesas, such as El Corazon, the Gavilan, Mesa Rico, Mesa Redondo, the big and little Huerfano, Mesa Tucumcari and others, every stratum of their red, brown and white beds being visible in horizontal bands for scores of miles.

The western border is the foothills or hogbacks of the eastern front of the Rockies. The northern border from Trinidad to Folsom is the northern escarpment of the so-called Raton mesa, the foot of which is followed by the Denver and Fort Worth railway. The eastern border is less conspicuous, for it is the baseleveled shore line of the Llano Estacado formation.

This region possesses a diverse surface aspect, consisting as it does of various erosion plains upon which stand great remnantal mesas of sedimentary and eruptive rock sheets, like Raton mountain and Fishers peak—remnants of the atmospheric erosion of Tertiary and Pleistocene time. The region as a whole, however, is a series of stratigraphic plains produced by degradation from one hard bed of stratification to another in successive steps from the Fishers peak basaltic sheet, which caps the highest mesas, to the Laramie sandstones; from these to the calcareous flaggy layers of the Colorado shales, as at Springer and Las Vegas; and from these down to the basal Dakota sandstones with the white band of the Trinity which forms the foundation of the series, as in the Canadian valley and the accompanying Corazon escarpment. The Red bed floor is finally reached, below the white band of Trinity sandstone, some 10,000 feet below the highest summit of the old plateau.

The plateau or shoulder as a whole is a product, then, of the unequal erosion of the sub-horizontal beds of the upper Cretaceous from the Laramie to the Dakota, inclusive, which are here included between the Red bed floor and the Fishers peak basalt. This erosion from top to bottom of the successive plains of stratification has partially removed more than 5,000 feet in thickness of sedimentary strata; and there is no evidence that the region has ever been submerged since Cretaceous time, either during the Llano Estacado or the basin epochs mentioned elsewhere. In fact, it was the stream-worked land whose débris furnished much of the sediment for the rocks of the last-mentioned periods. It is the remnant of a great plateau (the Tertiary land) which existed around the southern half of the Rocky mountain uplift before the Llano Estacado (Neocene) epoch, during which the larger mass of the plateau was degraded or baseleveled and was the shore line of the great coastal plain now represented in the Llano Estacado deposits. During this epoch much of its unconsolidated mass was removed, and reappears as the silt of the Llano Estacado formation. The later Pleistocene erosion has still further degraded the plateau and reduced its thickness and extent.

The Llano Estacado.

For those portions of the great plains proper lying east of the Raton-Las Vegas plateau, south of the Cimarron river and east of the Pecos, the term Llano Estacado was appropriately applied by the early Spanish explorers, but the term is now usually restricted to the portions south of the Canadian. In surface features the

northern half of this plain is similar to that of the Tertiary plains of eastern Colorado, Kansas and northward, but it differs from them in that, instead of extending to the Rocky mountains on the west or imperceptibly grading into the level of the eastern areas, it is surrounded on every side (except a few miles at the southeastern corner) by a more or less marked and often precipitous escarpment of erosion which completely insulates it from all other regions, except the Edwards plateau toward the southeast, which is its direct coastward continuation and genetically a portion of it.

Within the past few years the new railroads of Texas and New Mexico have made accessible to the geologist this greatest of all the plains, and perhaps areally the largest and least studied plateau of our country. Geographically it includes the quadrangular region south of the Canadian, east of the Pecos, and west of the one hundred and first meridian. The scarps which surround it are very irregular and least conspicuous upon the eastern edge, and are marked by many deep, vertically incised cañons, such as canyon Blanco, which is nine hundred feet deep. Easterly projections of these plains extend down the principal drainage divides, and probably were once continuous across the present denuded region to the Grand prairie, as is still the case with the divide of the Pecos and Colorado. The northern and western escarpment valleys, *i. e.*, those of the Canadian and Pecos, are more precipitous, being over 1,200 feet deep, and receive none of the surface drainage of the plain, owing to the diverse slope. The surface of this plain is nearly smooth and unbroken except at its edges, and constitutes as a whole the largest area without surface drainage in our country. It slopes eastward to the rate of 20 feet per mile, and its greatest elevation, at the northwestern corner, is 5,500 feet. Hydrographically the whole surface is void of running streams, and the small amount of surface water not imbibed by the soil is found in a few widely distributed ponds. Its eastern and northern edges are incised by deep, vertical canyons of tributaries of the Red, Brazos and Colorado systems, which are cutting into it by retrogressive or headwater erosion. Two streams have cut completely through the plains and into the Red bed and Cretaceous floor; these are the Canadian and Pecos. But neither of these receives any of the surface drainage of the plain and both are true mountain streams.

The residual soil of the plain is mostly composed of the transported sedimentary débris of the Rocky mountains and the Las Vegas plateau. From its structure and composition it is evident that the soil is a littoral or alluvial deposit laid down in late Tertiary time. This soil differs from most others in Texas, and. notwithstanding the deficient rainfall, the plains are being rapidly settled by an industrial population.

The geologic structure of the Llano Estacado is as simple and uniform as its topography, consisting of a surface sheet of unconsolidated porous sediments, composed mostly of water-worn gravel, sand and silt occurring in horizontal layers, averaging 200 feet in thickness throughout its extent, as ascertained by numerous well borings and measurements of the escarpments, and deposited unconformably upon the various older rocks which constitute its floor. The greatest thickness of the formation is toward the northern margin of the plain, and it gradually thins southeastward.

The peculiar heterogeneous character of the unconsolidated formation has been well described by Professor Robert Hay as grits, mortar beds and marls. Certain layers are composed of hard siliceous pebbles, which are recognizable as the débris

of well-known Rocky mountain formations. Others consist of coarse water-worn quartz sand, loosely cemented by a lime matrix, so that they are literally coarse mortar beds. The silt is usually pinkish or light chocolate brown, and forms a rich agricultural soil when watered. Another typical aspect is known to the Mexicans as the tierra blanca, or white earth. This occurs as strata of white calcareous chalky matter possessing strong hydraulic or setting properties, and usually forms the protecting or cap layers of escarpments. It is composed of sulphate and carbonate of lime derived from the sediments of chalk and gypsum. The tierra blanca is well shown north of Toscosa in the bluffs of the Canadian, in the bluffs of the Palo Douro canyon, and in the railway cuts of the Texas Pacific west of Sweetwater, Nolan county. The surface sheet extends south of the Texas Pacific an indefinite distance on the Edwards plateau. It reaches the Rio Grande in Val Verde county, north of Del Rio, and I am inclined to believe that it once covered the whole of the Edwards plateau, and has since been largely eroded. There are closely related features in the neighboring coast regions of Texas and in the Rio Grande embayment.

The floor of the Llano Estacado, or that portion underlying the above-described cap-rock formation and outcropping as the basal portions of its escarpments, is more complicated but of great interest in the geologic history of the region, inasmuch as it represents a great baseleveled land which existed prior to the plains deposition. Its conditions and structure can best be conceived, however, by considering the present diversity of formations constituting the earth's surface, sands, clays, etc., and imagining a great subsidence which would reduce these to a common baselevel and spread over the various rocks a sheet of sediments similar to the Llano Estacado formation and the Lafayette of southeastern United States.

South of the 32d parallel this floor, which becomes the surface by the still later denudation of the Llano formation, is composed of the rocks of the Comanche series, from the Trinity sands to the Caprina limestone mostly, the latter formation constituting by far the greatest area, extending over thousands of square miles in the counties of Midland, Ector, Tom Green, Pecos, Coke, Glasscock, Crane, Upton, Irion, Menard, Crickett, Sutton, Kimble, Edwards, Val Verde, and Kinney. Toward the northwest this floor was eroded down to the Trinity sands, and even these were worn away over the greater portion of the vast area previous to the plains deposition.

The remnantal Trinity sands occur beneath the escarpment of the plains along the eastern slope of the Pecos valley, at the Headquarters ranch, east of Eddy, New Mexico, where the limestone and clay beds have completely disappeared. The sand hills of Texas and New Mexico, at the foot of the western escarpment of the plains, are probably in large part remnants of the formation. These sand hills cover hundreds of square miles along the western (or Pecos) escarpment of the plains in various counties of Texas and eastern New Mexico.

Along the northwestern escarpment of the plains and along many of the buttes and mesas of the Red River valleys there is another outcrop of what may also be considered the Trinity sand. There is no evidence of its presence along the entire northeastern quarter in the canyons of the Red and Canadian rivers. Wherever this sand is found it indicates the great degradation which the pre-Llano Estacado deposits have undergone and the important place they occupy in the geologic history of this country. This degradation is worthy of especial attention, for it was even greater than that which has taken place since the Llano Estacado deposition. By the Neocene baseleveling an inestimable amount of the Red beds

and the upper and lower Cretaceous sheets, as well as the rocks of the mountains proper, were degraded and redeposited. Especially is this true of the great rock sheets of the Comanche series, so fully developed to the eastward, and the absence of which to the westward in the Rocky mountain region has so long been a subject of perplexity. They had already suffered much degradation in the baseleveling which took place during the Dakota epoch, and the degradation of the Llano Estacado epoch still further reduced, almost obliterated, the remainder.

The great canyon of the Canadian lying between the northern escarpment of the Llano and the southern escarpment of the Raton-Las Vegas plateau averages 40 miles in width, and is 200 miles in length and 1,200 feet in depth. This is an undoubted valley of erosion, which has removed 8,000 square miles of the plains and 2,000 cubic miles of the earth. The valley of the Pecos from the mountains to the Texas line has removed a similar amount. On the eastern margin, over the vast central denuded region, the erosion is just as plain to a geologist. The eastward-projecting tongues forming the divides of every stream from the Platte to the Llano all testify that they are but the rapidly decaying remnants of the greater areas that have been destroyed, and these divides extend as far east as the 98th meridian.

There is still further evidence of this eastward extension in two interesting areas, the Edwards plateau and the Washington and Fayette prairies of the east.

The Edwards Plateau.

The Colorado river cuts a very deep canyon through the Grand prairie in Travis and Burnet counties, separating the central or Fort Worth area from the southern or Edwards plateau. The latter is that portion of the Grand prairie south of the Colorado and east of the Pecos. Its width from east to west is greater than its length from north to south, and as it lies mostly within the truly arid region it is not well adapted to agriculture. Its surface is more uniform than that of the arid Llano, being composed of hard limestone strata which terminate on all sides by descending fault escarpments, instead of dipping beneath some newer formation as do all the rock sheets of the northern divisions of the Grand prairie. This region has hitherto had no specific name, being usually called "the mountains," from the escarpments which surround it. It is now proposed to call it the Edwards plateau, from Edwards county, where it is greatly developed.

This plateau is one of the most extensive and unique topographic features of the whole region. It consists of a vast rocky plain of hard Comanche limestone, covered by a scrubby growth of oak, juniper, mesquite, nopal, and sophora (or false laurel). It is a good grazing country, but little adapted to agriculture, except on patches of alluvial soil in the creek bottoms, owing to the intense dryness of its rocky sub-structure. It, in conjunction with the Llano Estacado, is a typical plateau of the mesa type, its eastern and southern margins being everywhere marked by descending or step-off escarpments, the result of the great Balcones fault by which the whole Black prairie region east of it has dropped down from 500 to 1,000 feet.

The downthrow east of this great fault is conspicuous only south of the Colorado-Brazos divide, some ten miles north of Austin. From that point southwestward to Del Rio, where it crosses into Mexico, it becomes more and more conspicuous as a great escarpment line, visible to the westward of the International railway as far south as San Antonio, and from that point westward, north of the

Southern Pacific railway to Del Rio, the directions of the portions mentioned of both of these roads being controlled entirely by it. To this eastern escarpment of the Kerrville plateau the Mexicans have applied the appropriate name "Balcones."

The northern border of the Edwards plateau is marked by the southern wall of the Colorado canyon from Austin to Travis peak as an irregular escarpment of erosion running westward through San Marcos and McCullough, forming the boundary of the Llano-Mason Paleozoic area. It turns westward and southwestward through Concho and southern Tom Green counties, and thence irregularly forms the breaks of the Concho river; and it merges with the Llano Estacado in Howard, Martin, Tom Green and Midland counties. It is a true escarpment of erosion.

An examination of the map will show that the Edwards plateau proper east of the Pecos occupies many thousand square miles, including most of the counties of Pecos, Edwards, Crockett, Schleicher, Val Verde, and Bandera and about one-half of the counties of Kinney, Uvalde, Bexar, Cornal, Hays, Concho, Tom Green, Irion, Upton and Crane, and a small portion of Travis. In Upton and Midland counties the rocky surface of the plateau becomes the prevalent floor of the peculiar Llano Estacado formation which extends thence northward. Its narrowest width is found along the 32d parallel; after crossing this narrow neck, about fifty miles in width, the western escarpment is reached, forming the eastern breaks of the Pecos valley, and continues southward along that stream forming a valley from 500 to 1,000 feet deep to the Rio Grande. In fact, the Edwards plateau is but the southern continuation of the floor of the great Llano Estacado plateau, the same deposition level from which the Llano Estacado formation has been mostly eroded.

The greater part of the summit of the Edwards plateau, like the Llano Estacado, is void of streams. Its eastern margin is indented by a number of streams, which are the most beautiful in the state of Texas. These streams usually have enormous canyons in proportion to their volume. They are mostly mountainous toward their headwaters, but near the point of emergence from the Balcones escarpment they flow through their own débris in canyons and valleys vastly out of proportion to their present volume, which no doubt represent the ancient sea level of the Rio Grande embayment.

It will be well to observe that there are no sharp topographic or structural barriers between the Edwards plateau and the Llano Estacado, and that any difference between them is in the surface formation and due to the greater erosion of the eastern border. Taken together they constitute a single vast mesa 500 miles long and 280 miles wide, surrounded on all sides by escarpments, all of which have their origin in the underground water of this vast mesa. While composed of the same strata as the northern extension of the Grand prairie, the Kerrville plateau, topographically and genetically, should be considered a portion of the Llano Estacado. Another interesting fact of the Edwards plateau is the series of ancient volcanic necks along its southeastern margin, from Austin to Del Rio, to which I have previously given the name of Shumard knobs.

The Red, Brazos and Colorado and also the Rio Grande have cut deep into and in places entirely through the formation of the Grand prairie (the Comanche series), and their valleys present the same atmospheric terracing as the western border. In places these river valleys assume the aspect of vertical canyons, as in the Colorado, Pecos and Rio Grande. The depth of these valleys below the level of the plain increases southwestward from 200 to 700 feet.

The degradation which the northern borders of the Edwards plateau and its

continuation, the western margin of the main Grand prairie, have suffered is enormous, for it together with the former westward extent of the upper Cretaceous and Eocene and the eastward continuation of the Llano Estacado have been removed in Neocene time from almost all of the central denuded or Paleozoic region of Texas—a simple and evident fact, yet so large and profound as not to have been recognized by local geologists. This denuded material has all entered into the structure of the Coast and Fayette prairies, the material and vast extent of which alone, if topographic proof were lacking, would be sufficient to demonstrate the great denudation.

The genesis of this vast plain, the Llano Estacado and Edwards plateau, has long puzzled me, for I have tried to make it harmonize with the lacustral doctrine by which its northern extension in Nebraska and Dakota has been explained. This lacustral doctrine, as applied to the Laramie and other post-Cretaceous phenomena of the west, necessitates a hypothetic land barrier between the eastern escarpment of these plains and the coast in an area now actually occupied by valleys of erosion, and without any evidence whatever, structurally or otherwise. Thanks to the investigations and direct suggestion of Mr. McGee, I am now inclined to consider it the interior margin of a great littoral sheet of deposits which extend to the Gulf. Although this hypothesis involves the erosion in post-Tertiary time of nearly 200,000 square miles of area, it is sustained by three important lines of evidence:

1. The great land stripping at present going on in the central region, and the eastward succession of the scarps of the series of the coastward incline.

2. The deep incision by the older rivers of this coastal plain, the Brazos and the Colorado having cut 1,000 feet below it.

3. The actual remnants of the plain over the denuded area, occupying the divides of the drainage.

4. The existence beneath the coastal clays in eastern Texas of a great formation, tion, which may prove a continuation of the Llano Estacado sheet.

THE WASHINGTON PRAIRIES.

Immediately westward of the coastal prairies (which it will be remembered are composed of unconsolidated clays) there is another region, of which the chief characteristic is a rich, black, sandy soil, derived from the disintegration of a friable sandstone, composed largely of well rounded and polished grains of quartz cemented by a white calcareous matrix—a great water-bearing formation which dips beneath the coast clays and supplies the artesian waters of that region.

These prairies have been mapped out by Dr. R. H. Loughridge, and the underlying formation has been described by Roemer, Shumard, and Penrose, the latter proposing for it the name of Fayette sands.

These sands have a remarkable resemblance to the deposits constituting the Llano Estacado formation, and contain also the peculiar opalized wood and fossil bones and leaves characteristic of that formation, and it is probable that they are the same or a closely allied terrane which once extended continuously over the entire region; and I am also inclined to believe, with Shumard and Roemer, that they are of Miocene or Pliocene age, rather than Quaternary, as asserted in the Report of the Texas Survey.

Dr. B. F. Shumard, in 1861, correlated this formation with the great plains and announced* "the discovery, in Washington and adjoining counties, of an extensive

*Trans. St. Louis Academy of Science, vol. 2, 1868, pp. 140, 141.

development of * * * Miocene deposits of the Mauvaisse-Terre formation of Nebraska [White River and Loup Fork] which have yielded such a wonderful profusion of extinct mammalians and chelonians. The Texan strata consist of calcareous and siliceous sandstones, and white, pinkish and grayish siliceous and calcareous marls. The calcareous beds are almost wholly composed of finely comminuted and waterworn shells, chiefly derived from the destruction of Cretaceous strata, and in places abound in fossil bones and plants, usually in a fine state of preservation. The bones * * * consist of genera closely allied to or identical with *Titanotherium*, *Rhinoceros*, *Equus*, and *Crocodilus*."

If these relations between the Llano Estacado and the Washington prairie be true, the great difference in level (there is no appreciable difference in dip) must be explained, and to appreciate this we must first study the large area known as the Rio Grande embayment.

The Rio Grande Embayment.

I have previously explained how the climatic features of all the coastal plain change south of the Colorado or the Guadalupe, and how the great Balcones fault escarpment becomes more arid and generally different. This region southward includes the continuation of the coastal prairie, the Washington prairie, the Timber Belt Eocene, and the Black prairie, and includes all the Rio Grande counties as far west as Val Verde, embracing all of Maverick, Encinal, Duval, Nueces, Webb, Dimmit, La Salle, Starr, Zavalla, Frio, Atascoso, Karnes, Goliad, Refugio, San Patricio, Wilson, Aransas, Cameron and the southern or eastern portions of Uvalde, Medina, Bexar and Guadalupe. The 97th meridian, which is accepted as the western limit of reliable rainfall, intersects the gulf at Aransas Pass and is the eastern limit of the region; and if reports be true, the lower part of the region, at least, is certainly one of the arid portions of Texas, a drouth of over eighteen months' duration having been recently reported from Hidalago within 100 miles of the coast. The rainfall, however, is much greater toward its interior margin, from San Antonio to Del Rio, where the drouth has not extended.

This region is in many respects the least studied portion geologically of Texas. Its predominant and topographic feature is its generally low altitude, the contour or line of equal altitude of 600 feet, which marks its western margin, making a great deflection westward along the Balcones escarpment and up the Rio Grande to Eagle Pass, and thence back toward the coast on the Mexican side, constituting a great indentation, as if it had been a bay of the gulf covering the region in comparatively recent time;* and this is further proved by the great deposits of Pleistocene gravel and conglomerate marking its interior border and indicating late deposition of at least two formations, and which remains in places over much of the area, though greatly denuded by a still more recent and restricted elevation, as seen nearer the Rio Grande valley. I am inclined to believe these sedimentations to be of late Neocene and Pleistocene age and closely connected with the Llano Estacado and Basin epochs of the northwest. The oldest and furthest inland of this débris, visible from San Antonio to Uvalde, is only a thin and inconspicuous sheet found at the ancient margin of the Edwards plateau.

The fundamental structure underlying these surface sheets in this vast region is the system of rock sheets from the Eagle Ford (Benton) shales (bordering the fault

*This embayment commenced at the beginning of the upper Cretaceous or Dakota epoch, and was repeated many times.

escarpment from San Antonio to Uvalde) on its interior margin to the coastal prairies and clays at the coast, with slight variations from the same beds seen in Texas north of the Guadalupe. This includes a great thickness of unconsolidated beds. Succeeding the chalks and clays which overlie them, there is a great development of sand and sandstones in the glauconitic divisions of the upper Cretaceous which here is quite different paleontologically (owing to the different conditions of original sedimentation in this Rio Grande embayment) from the Arkansas-New Jersey development. These uppermost Cretaceous beds, for which I have proposed the name of Eagle Pass beds, outcrop from west of Eagle Pass to the Webb county line along the Rio Grande, and occur all over the embayment as far southward as the Santa Rosa mountains in Coahuila, constituting its predominant formation. Succeeding these are various beds of the Eolignitic, Fayette (Neocene) and coast prairies; the Fayette corresponding at least in part to the Lafayette, and the coast prairies to the Columbia, of McGee.*

This embayment is a structural feature and primarily the product of an orogenic event associated with the Rocky mountain uplift, which began in the late Cretaceous time and reached its culmination after the close of the Mesozoic, and is distinctly recorded in the conspicuous features of the Balcones fault and the mountains of northern Mexico. Its further development is a record of subsidence and elevation from the above-mentioned epoch to the present time, during which the shore line projected and retracted toward the present coast, with changes of baselevel, to interpret which will require much study.

This orogenic movement was the faulting and folding of the great floor of horizontal chalky limestones of the Comanche series, which extended as an almost uniform dip plain (like the present portion between Red and Colorado rivers) from the Ouachita mountains of Indian Territory to central New Mexico. The movement resulted in the folding, metamorphism and consolidation of the rocks of the southwestern portion of this plain in Coahuila and trans-Pecos Texas, and produced lines of weakness which, by the loading down of the Tertiary and Quaternary plains, developed into the great Balcones fault, extending at right angles to the axes of the Coahuila mountain blocks from Del Rio via Uvalde, San Antonio, Austin and Round Rock, a distance of 200 miles. This fault was first pointed out by Professor E. D. Cope, and is one of the most conspicuous features of Texas. It was the downthrow of this fault that constitutes the Texas margin of the Rio Grande embayment, and along the escarpment line are great deposits of littoral and estuarine gravel and river terraces, which are the records of the late Tertiary and Pleistocene baselevels. The summit or plateau west of this fault line has been already mentioned as the Edwards plateau.

Upon the opposite or Mexican side, beyond the valley of the Rio Grande, an analogous condition exists, the great difference being that the plateau, which in Texas extends inward from the interior margin, is there broken up into mountain blocks and is completely surrounded in some cases by the Pleistocene deposits.

Around the margin of the interior of the embayment there are evidences of igneous activity, consisting of volcanic necks on the Texas side, the flows from which, if they ever existed, having been destroyed by post-Tertiary erosion. In the Sabinas valley of Mexico fragments of the flows are preserved, but show Pleistocene degradation on every side.

It is my present opinion that the great fault separating the Edwards plateau

* 12th Ann. Rep. U. S. Geol. Survey, 1892, p. 502.

from the Rio Grande embayment was accentuated, after having already begun in late Cretaceous time, by the loading down of the embayment during Pliocene and Pleistocene time with coastal sediments, thereby breaking the present hysometric continuity of the ancient Llano Estacado baselevel to the coast.

Basin Deposits of the Trans-Pecos Region.

Character of the Basins.—In addition to the vast sheet of Llano Estacado deposits in Texas, Kansas, Colorado, Nebraska and northern New Mexico, which are surrounded more or less upon every side by descending escarpments of erosion, there are many large areas of a somewhat similar but newer formation occurring in valleys eroded in the plains or enclosed by mountain blocks occurring as flats or basins between the mountains, often many hundred miles in length. These so-called basins laying between the mountains constitute nearly all of the irrigable and tablelands of the region west of the Pecos.

The Rio Grande flows most of the way in basins for five hundred miles south of Albuquerque to a point near the Quitman mountains, except at the mountain passes at the southern ends of the Mesilla and the Jornado basins respectively. The river has cut far into and below the latest level of the basins. Below El Paso, near Fort Hancock, the depth of the lacustral deposit cut through is twelve hundred feet, and the river has almost reached the ancient hard-rock floor.

The Hueco-Organ Basin.—One of the most extensive and characteristic of these great inter-mountain basins of post-Tertiary sediments is that lying between the Organ-Franklin and Hueco-Sacramento ranges in extreme western Texas and southern New Mexico. This vast expanse of apparently "deadlevel" plain, extending from the Rio Grande northward some 150 miles, is from 90 miles in width at its southern end to 40 at its northern. The Rio Grande cuts through its southern end, exposing a grand section of the structure from El Paso on its western side to Etholen station on the east. The basin, although apparently level, slopes southward, according to the Whiteoaks railway profile, from 4,500 feet at its northern end to 3,500 feet at its southern end.

On all sides this flat or basin (locally called "The Mesa" at El Paso) is surrounded by high mountain blocks, including the Juarez, Franklin-Organ and San Andres blocks on the west and the Sierra Blanca, Hueco and Sacramento blocks on the east, all composed of hard, impervious, metamorphosed limestones, quartzite, granite, porphyry and basalts, the stratified rocks being of all ages, from the Silurian to the Cretaceous.

The soil of the basins resembles that of the Llano Estacado, and is the residuum of the substructure of loose or unconsolidated sands (grits), "tierra blanca," clays and water-worn gravel. Around the margin of the basin near the mountains there are great fan-shaped benches of débris from the mountains, distributed by the torrential streams running down the slopes and covered with sotol and yucca, the foothill flora of the region. These marginal deposits constitute extensive terraces in places and are composed of boulders of mountain rock of all sizes and shapes.

The structure of this basin formation is beautifully shown in the escarpments or mesas of the Rio Grande valley east of El Paso, where the "tierra blanca," or calcareous conglomerate, can be seen capping the scarp, and in the bluffs along the railroad between Etholen and Fort Hancock, where the soft, disintegrating escarpment has every aspect of the typical "bad land" formations of the arid regions.

These beds, like all the post-Tertiary deposits, are chiefly marked by their nonconsolidation, the sands, clays and gravel being almost as loose as when first deposited. White chalky lime strata, or "tierra blanca," resembling the Cretaceous beds, are numerous; but upon examination they are always found to be conglomeratic and composed of débris of the "jeso," or decomposed gypsum of the Red beds, and the chalky strata of the Cretaceous, mixed with the mountain débris.

These beds were clearly laid down in the mountain troughs or valleys by lake sedimentation, and are of later age than the Llano Estacado formation. They never enter into the disturbed mountain structure, but are deposited unconformably like a matrix around the mountain bases. Their depth or thickness would be difficult to estimate, but it varies from nothing at the mountain edge to at least 1,000 feet in thickness in the southern center of the basin.

The northern end of this valley or basin presents several peculiar phenomena, the principal among which are the celebrated white sands. These are composed of rounded grains of gypsum instead of silica, and throughout their extent water is easily secured by digging a few feet. The northern end has also been covered by a great flow of lava or "malpais," mentioned later on, which it is alleged flowed down the valley some thirty miles from the alleged craters in township 10, range 10, first standard parallel. Although this flat or valley has not upon its surface a single running stream or even a drainage channel, so that its surface is the most complete picture of aridity imaginable, yet beneath it lies an illustration of one of the most important artesian basins in the west. The rainfall in this region is mostly upon the mountains that surround the basin, standing some 3,000 feet above its plain, and the water flows rapidly down their sides until it reaches the plain. Many of these streams, like the Rio Tularosa and the Tres Rios, are perennial, and others all along the mountain range carry great volumes of water during the winter and autumnal seasons. Immediately upon leaving the impervious mountain rock and upon reaching the plains these streams disappear completely, a phenomenon which cannot but impress the observer with wonder and astonishment. They do not evaporate, as has been alleged, nor do they sink into caverns, as most people think, but they are imbibed, literally drank up, by the soft, sponge-like formation of the plain, and are stored below the line of saturation. The shedding of its rain-waters by the impervious mountain rock and its imbibition by the spongy plains rock is the key to the whole question of underground waters in the arid region, for not a single flowing well has ever been obtained west of the 100th meridian and south of the Dakotas in the consolidated mountain structure.

The Hueco-Organ basin is accompanied by many terrace benches around its border. These are of two kinds: (1) remnants of ancient shore lines; and (2) delta deposits of débris brought down by present floods upon the mountains. The terraces are especially well shown in the pass of the Rio Grande at El Paso, where on the northern side seven or eight tiers of them above the river level can be traced.

The Mesilla Basin.—West of the Organ-Franklin range there is another extensive basin which is occupied by the valley of the Rio Grande and extends from near old Fort Selden to Frontera, four miles west of El Paso. This basin is bounded on the west by small mountain blocks running north toward the Fort Selden eruptives. In this basin are situated the towns of Mesilla and Las Cruces, two of the most flourishing places in New Mexico, and extensive agriculture is carried on by irrigation from the Rio Grande.

The formation of this basin is the same as that of the Hueco-Organ basin, and

at certain stages it was no doubt continuous with that of the latter valley. The river, which leaves the consolidated mountain rock at Fort Selden has cut deep into this plain, and much of its waters are imbibed by the porous formation until it again enters the mountain rock near El Paso.

The Jornado del Muerto Basin.—The northern end of the Mesilla basin or plain is terminated by a group of stratified and volcanic hills, which extend westward from the Organs, via Donna Anna and Fort Selden, cutting off the Mesilla basin from that of the Jornado del Muerto, which begins north of this barrier and extends northward for a hundred miles. This is perhaps the most noted of the basin plains, having been long celebrated for its absolute lack of surface water, and lying directly in the track of the ancient Santa Fé-El Paso trail.

The Jornado occupies the country north of the Donna Anna hills from Fort Selden northward. On the east its limits are the San Andres and Sierra Oscura, the northward continuation of the Organ range. On the west it is bounded by the Sierra de los Caballos and Fra Christobal, the southern continuation of the Sandia range. The Atchison, Topeka and Santa Fé railway enters it at Socorro, and continues upon it northward to Lava station.

This basin was partially described by Dr. G. G. Shumard * as follows: "Wherever examined the surface formation was found to consist of detritus of rocks in all respects the same as those composing the neighboring mountains from which it was doubtless mainly derived. The precise thickness of this deposit could not be very accurately determined, as only a few natural sections were observed, and these only near the base of the mountains. In two localities its observed thickness was nearly five hundred feet."

The Eagle Flats Basin.—Another and extensive formation lies between the parallel mountain ranges of the Quitman-Muerto series (which is a continuation of the Hueco series) and the Diablo-Davis series. This basin is of irregular area and has two principal arms or members, the southwestern of which is traversed throughout its greatest length by the Southern Pacific railroad from Sierra Blanca to Marfa, and is known as the Eagle flats. This is a very narrow basin, seldom exceeding twenty-five miles in width, and like the others is surrounded on all sides by mountain blocks, against which may be clearly discerned the terrace structure of the ancient lake shores. The soil is the same pink-tinted gravelly loam of all the mountain basins.

From Sierra Blanca this basin sends another arm eastward and northward up the eastern side of the Hueco series and west of the Carizzo and Diablo mountains toward the Wind mountains for an unknown distance. In this portion of the basin there are several salt lakes of small area and extent. The Texas Pacific crosses this portion of the area, east of Van Horn, through a mountain gap.

Valley of the Salt Lake Basin.—Another vast basin extends along the meridian of 104° from the southern end of the Guadalupe, north of Wildhorse station on the Texas Pacific. The basin is about thirty-five miles from northwest to southeast and half as wide, and is marked by numerous salt lakes. It is surrounded on the west by the mountain blocks of the Sierra Diablo, on the north by the Guadalupes, and on the east and south by low unnamed mountain blocks. From descriptions, this

*The geological structure of the "Jornado del Muerto," New Mexico, being an abstract from the geological report of the expedition under Capt. John Pope, U. S. Top. Engrs., for boring artesian wells along the line of the 32d parallel; by Dr. G. G. Shumard, M. D., geologist of the expedition: Transactions of the Academy of Science of St. Louis, vol. i, 1856–'60, p. 341.

must be one of the most interesting of the great basins, but the writer has been unable as yet to visit it.

Basin of Mimbres.—West of the chain of mountain blocks, including the Floridas and Los Mimbres-Black range groups on the east, and the Sierra Baca, Pyramid, Hatchet, Burro and Black ranges on the west, there is another vast basin into which drains the river known as the Mimbres and numerous other typical lost rivers, most of which come from the Mimbres and Black mountains. This basin, with its southern extension the Florida plains, includes about fifty townships, or 9,000 square miles, in the United States, and at least as much more in Mexico. Its surface presents the same level topography and its formation is composed of the same lacustral débris as in the other basins mentioned, and like them it has a drainage slope southward.

The northern end of this valley receives nearly all the mountain waters from the Black and Mimbres ranges, and like the Franklin-Hueco basin is characterized by numerous lost rivers. One of these, Los Mimbres, is the most conspicuous of all the lost rivers of the west, and has been the cause of much speculation and wonder. It is a boldly flowing mountain stream until it gets well out upon the plain, when it completely disappears by imbibition and evaporation.

Probable Basins of the Pecos Valley.—The Rio Pecos, from the mouth of Delaware creek to Pecos city, fifty miles below, and thence to an undetermined point some fifty miles further southward, flows in grits and clays of the typical basin character, which, together with the topographic conformation and well-boring records of the region, lead to the belief that this portion of the Pecos valley is another Quaternary basin. The escarpment of the Llano Estacado is far east of Pecos city, and the river flows in a flat or basin some thirty miles wide from Toyah to Quito, which seems entirely unlike a river floodplain. This flat is marked on the east by a high scarp line near Quito, 12 miles east of Pecos city, but inasmuch as the apparent shore-line formations were of the softer Red beds and plains formations, instead of the harder mountain rock like that of the other basins, it is difficult to say, after my brief studies, whether or not it is a true shore line, although I am greatly inclined to think it is. The western shore of this apparent basin is the west of Toyah, against the eastern slope of the Davis mountains. Both at Pecos city and at Toyah numerous artesian wells have been found in this alluvial deposit, whether it be of lake or river origin.

The Volcanic Areas of eastern New Mexico.

Besides the older eruptive rocks of the mountain proper, large areas of the plain and basins of New Mexico and Mexico, though not of Texas, are covered by heavy volcanic flows of lava and basalt hundreds of square miles in extent. In many cases these are accompanied by cinder cones or craters; others are fissure extrusions; and in still others the sources of the flows have not been determined. These lava sheets are especially conspicuous in the vicinity of many of the ancient basins previously described, and their proximity suggests that there is a close relation between them.

The Raton-Las Vegas plateau was originally capped by a vast sheet of basaltic lava, which is still the determinative or initial feature in the erosion of the plain of that vast region, which has been mostly worn away. It still surmounts Fishers peak, south of Trinidad, and the great Mesa de Maya, extending fifty miles eastward.

It also caps the Eagle mountains and vast areas to the southward as far as Las Mora creek. The source of this basalt is undetermined, but it is supposed to have flowed from fissures and not from craters in early Tertiary time. At a lower altitude and apparently of later age, along the eastern border of this ancient basaltic flow, at its contact with the Llano Estacado formation, and in the vicinity of Folsom, there is a group of volcanic craters, composed of cinder cones of from 100 to 2,750 feet in height above the plain, from which have been extruded vast sheets of lava and basalt, covering the country for miles around and extending more or less irregularly from Folsom to Rabbit Ear mountains near the Texas line, 100 miles distant and north and south of the road about 50 miles, partially covering an area of 1,000 square miles. The most conspicuous of these craters is Mount Capulin, six miles south of Folsom station. This, a beautiful cinder cone (altitude, 9,000 feet), rises nearly 2,750 feet above the railroad, with a vast crater at its top nearly a mile in diameter, slightly broken down on its western side. From its summit many flows can be traced.* To the southward from six to twenty miles there are several similar craters, while to the northward there are several smaller ones, called monteules by the Mexicans. Around these craters there are numerous flows of vesicular, ropy lava.

These are the easternmost known craters of the Rocky mountain region, and their occurrence at the contact of the Llano Estacado shore line (or deposition level) and the Raton plateaû is interesting. The cinder cones are clearly of a more recent origin than the adjacent basaltic cap of the Raton plateau, for they are situated in an eroded valley between the main mesa and an outlier—the Sierra Grande—and at a lower altitude than either of them. They are also apparently more recent than the late Tertiary deposits of the Llano Estacado, the original surface of the lava resting upon the latter and not covered by it except in case of the wind-blown débris.

For two hundred miles southward no more of these craters are encountered until we reach the head of the Hueco-Organ basin, between the San Andreas and Guadalupe mountains, on the stage road from Socorro to Fort Stanton. Here again there is a great area of "malpais" lava, which is a terror to the traveler and a barrier to the development of the country which it covers.†

The northern end of the floor of the Mesilla basin is covered by another lava flow, through which the railroad cuts at Fort Selden. Picocho peak and several others, some ten miles west of Mesilla, are volcanic cones. Of these Dr. G. G. Shumard says: "From the character and general appearance of these cones and lava streams I am disposed to ascribe their origin to a comparatively recent geological period. They form part of an extensive volcanic chain, which may be traced north and south for several hundred miles."

The northern end of the Jornado del Muerto basin also is occupied by a great lava sheet, 12 by 8 miles in area, or 96 square miles. This, too, is alleged to have come from a crater, about 10 miles east of the road, and bears the same intimate relations to the basin floor as the other crater flows mentioned.

Another crater flow upon the floor of the basin is about 30 miles northwest of El Paso, between Aften and Aden stations, where there is an alleged cone of great mag-

*A brief notice of Mount Capulin was published by Orestes St. John in "Notes on the Geology of Northwestern New Mexico": Bull. U. S. Geol. and Geog. Survey of the Territories, vol. ii, 1876.

†Since this paper was begun Mr. Ralph S. Tarr has published a brief description of this flow (see American Naturalist, June, 1891).

nitude, from which a narrow stream of lava flows southeastward about 20 miles. There are other areas in western New Mexico of volcanic lava, notably that south of Grand station, on the Atlantic and Pacific railway.

In Trans-Pecos Texas no craters have been noted, although they may occur in the mountainous regions. Many old volcanic pipes or necks without lava flows occur between Austin and Del Rio, but they are of entirely different type and age from those of New Mexico. The relation of those cinder cones and sub-recent flows to those of northwestern New Mexico and Arizona cannot be stated from personal observation.

Proceeding southwestward into Mexico they still continue, and in cases exhibit evidences of activity, increasing southward toward the neck of Mexico where the present epoch seems to represent but a southern continuation of the volcanic and lacustral conditions which so recently prevailed over the northern portion of the basin region.

The fact that these cinder cones and lava flows occur in the floor of the Quaternary lake basins is indicative of their recent origin. It is possible that future investigations will show an intimate connection between the drying up of the basins and the activity of these volcanoes.

It is also evident from the investigations that eruptive activity has occurred in the Texas-New Mexican region from Cretaceous to the present time, and at least three well-defined epochs are at present recognizable which may serve as a guide to future observations, viz:

1. The Austin-Del Rio system, or Shumard knobs; ancient volcanic necks or laccolites bordering the Rio Grande embayment, begun in later Cretaceous time, the lava sheets of which have been obliterated by erosion.

2. The lava flows of the Raton system, which are fissure eruptions of Tertiary time, and which are only partially removed by erosion.

3. The cinder cones and lava flows of the Capulin system, which are late Pleistocene and which still maintain their original slope and extent.

The most valuable evidence of the recent origin of the craters in addition to their location in the post-Tertiary valleys is their perfect shape and preservation from the great erosion from which all of the older and more consolidated features of the country have suffered greatly. To one acquainted with the active erosion of this region, by both cloudbursts and wind, the preservation of an unconsolidated and fragile structure like the New Mexican cinder cones is the most convincing evidence of newness.

The foregoing features are presented without any attempt at broad correllation with the coastal or other regions of the United States, although they present a tempting field therefor. For the present, however, I prefer to leave this task to others, hoping that the remarkable Tertiary and Pleistocene history will receive that attention which it deserves.

The following paper was then read :

THE RELATIONS OF THE AMERICAN AND EUROPEAN ECHINOID FAUNAS.

BY J. W. GREGORY, F. G. S., F. Z. S., OF THE BRITISH MUSEUM OF NATURAL HISTORY.

Contents.

Introduction.

Probably every paleontologist who lives on the western border of the great galearctic province occasionally chafes against the limitation which the Atlantic places upon our knowledge of the origin or derivation of successive fossil faunas. In many cases researches on the paleontology of central and eastern Europe have given the desired information as to the origin of a British or western European fauna; but in other cases groups of genera and species appear suddenly in a certain zone and as suddenly disappear. The probabilities in such cases are in favor of the mi-

Errata.

Page 101,	line 13	from bottom :	*for* "aquatic"	read	agnostic.
" 103,	" 6	" "	" "*karstein*"	"	*karsteni.*
" 105,	" 12	" top,	" "twinned"	"	tumid.
" 107,	" 27	" bottom,	" "*Asterostoma*, n. sp.,"	"	*Archæopreuster abruptus*, Greg.
" 107,	" 18	" "	" "*Asterostoma*"	"	*Archæopreuster.*

ence in the mid-Atlantic to explain the difficulties of paleozoological distribution in the old world: but, on the other hand, a school composed mainly of zoologists have adopted a more aquatic attitude by accepting the theory of the permanence of oceans and continents, which leaves these difficulties unexplained. Certain physical arguments have been adduced in support of this view, but they do not seem of any great value, and the whole question seems to turn on zoological, and especially on paleontological distribution. If the Atlantic has been permanently a deep ocean basin no such littoral tropical forms could have entered Europe from the west except during periods when the arctic area enjoyed a temperate climate, and a theory which postulates a series of such warm periods would be unsatisfactory even if there were not evidence in some cases against the "northwest passage."

The question is one of some importance to workers in most departments of paleontology. The phylogenist who accepts the theory of the permanence of oceans and continents is likely to train the branches of his phylogenetic tree along very different lines from those that would be preferred by one who admitted the possibility

nitude, from which a narrow stream of lava flows southeastward about 20 miles. There are other areas in western New Mexico of volcanic lava, notably that south of Grand station, on the Atlantic and Pacific railway.

In Trans-Pecos Texas no craters have been noted, although they may occur in the mountainous regions. Many old volcanic pipes or necks without lava flows occur between Austin and Del Rio, but they are of entirely different type and age from those of New Mexico. The relation of those cinder cones and sub-recent flows to those of northwestern New Mexico and Arizona cannot be stated from personal observation.

Proceeding southwestward into Mexico they still continue, and in cases exhibit evidences of activity, increasing southward toward the neck of Mexico where the present epoch seems to represent but a southern continuation of the volcanic and lacustral conditions which so recently prevailed over the northern portion of the basin region.

The fact that these cinder cones and lava flows occur in the floor of the Quaternary lake basins is indicative of their recent origin. It is possible that future investigations will show an intimate connection between the drying up of the basins and the activity of these volcanoes.

It is also evident from the investigations that eruptive activity has occurred in the Texas-New Mexican region from Cretaceous to the present time, and at least three well-defined epochs are at present recognizable which may serve as a guide to future observations, viz:

fragile structure like the New Mexican cinder cones is the most convincing evidence of newness.

The foregoing features are presented without any attempt at broad correllation with the coastal or other regions of the United States, although they present a tempting field therefor. For the present, however, I prefer to leave this task to others, hoping that the remarkable Tertiary and Pleistocene history will receive that attention which it deserves.

The following paper was then read :

THE RELATIONS OF THE AMERICAN AND EUROPEAN ECHINOID FAUNAS.

BY J. W. GREGORY, F. G. S., F. Z. S., OF THE BRITISH MUSEUM OF NATURAL HISTORY.

Contents.

INTRODUCTION.

Probably every paleontologist who lives on the western border of the great galearctic province occasionally chafes against the limitation which the Atlantic places upon our knowledge of the origin or derivation of successive fossil faunas. In many cases researches on the paleontology of central and eastern Europe have given the desired information as to the origin of a British or western European fauna; but in other cases groups of genera and species appear suddenly in a certain zone and as suddenly disappear. The probabilities in such cases are in favor of the migration of these forms from some western area. If the species in question possessed a great range, either in depth or of latitude, they present no especial difficulty; if their bathymetrical distribution was or appears to have been great, they may have come directly eastward; if they were spread over a wide area or were boreal forms, they may have worked their way around the shallow waters of the northern margins of the Atlantic. But there are cases that cannot be thus easily explained. The genera in question may be shallow water and tropical forms to which the deep and cold abysses of the Atlantic would present as insuperable an obstacle as an actual land barrier. If, as seems most probable, these forms did come from the west, how did they cross such a barrier, or was it in existence at that time? To solve the difficulties presented by such cases, many geologists have sought to give a scientific basis to the legends of the fabled Atlantis, and have called a new world into existence in the mid-Atlantic to explain the difficulties of paleozoological distribution in the old world: but, on the other hand, a school composed mainly of zoologists have adopted a more aquatic attitude by accepting the theory of the permanence of oceans and continents, which leaves these difficulties unexplained. Certain physical arguments have been adduced in support of this view, but they do not seem of any great value, and the whole question seems to turn on zoological, and especially on paleontological distribution. If the Atlantic has been permanently a deep ocean basin no such littoral tropical forms could have entered Europe from the west except during periods when the arctic area enjoyed a temperate climate, and a theory which postulates a series of such warm periods would be unsatisfactory even if there were not evidence in some cases against the "northwest passage."

The question is one of some importance to workers in most departments of paleontology. The phylogenist who accepts the theory of the permanence of oceans and continents is likely to train the branches of his phylogenetic tree along very different lines from those that would be preferred by one who admitted the possibility

of occasional direct intercourse between the southern palearctic and nearctic faunas. To the geologists and paleontologists who try to trace the origin and migrations of extinct faunas and their evidence as to the physiography of the past, the question is also of primary importance.

The evidence that would be most conclusive now, of course, lies buried beneath the Atlantic, and the paleontologist has to turn to America to see whether he can trace among its fossils the origin of any of the constituents of the old world faunas, and, if so, to see if he can discover when they entered the European area and by what route they traveled.

Any comparison of the European and American faunas that might be made with this end in view must be conducted with greater care than it would be possible for any one paleontologist to give to the whole of the evidence. A mere examination of lists of species is quite inadequate. Hence probably more reliable data can be gained from the detailed study of one group than from an attempt to handle all the available evidence; at least, this is all the present writer can attempt. The echinoidea offer especial advantages: the bathymetrical range of the species is fairly restricted; the deep-sea forms are very easily distinguished; the adults at least, and in some cases the young, are practically non-migratory; the echinoids are mostly tropical or temperate in habitat; they occur in abundance from the Carboniferous to the present; and, finally, as their classification rests upon the hard parts, their affinities can be more definitely decided than in the cases of most other classes. Hence in this paper attention is restricted to the echinoidea. It must, however, be admitted that conclusions based on one class alone are likely to be modified when the evidence of all the other groups is worked out. The final conclusion will probably be the mean of the results given by the independent study of the different divisions of the animal kingdom.

The Carboniferous Faunas.

Neglecting the problematical Silurian and the rare Devonian echinoidea as giving no adequate data for comparison, it is with the Carboniferous system that the species become sufficiently numerous to form definite faunas.

In Mr. S. A. Miller's useful "Catalogue of North American Paleozoic fossils" we find a fairly long list of Carboniferous echinoidea. Deducting one or two synonyms, the list stands as 41 species and 10 genera, to which must be added several new species recently described and several undescribed forms that occur in the American museums. Of this fauna of about 50 species, not one representative occurs in Europe. It is true that 20 of these belong to the genus *Archæocidaris*, and most of them have been based on spines and isolated plates; and that while the discovery of better material would probably reduce the number of species, it might at the same time demonstrate the identity of some of them with European forms; but at present I feel bound to admit that I have seen no evidence of the existence of any one Carboniferous echinoid on both sides of the Atlantic. The comparison of the genera is still more valuable and brings out a great difference between the two faunas. Of the ten American genera only three occur in Europe, viz, *Archæocidaris*, *Palæchinus*, and *Perischodomus*.* The other seven genera are peculiar to

* *Eocidaris* may seem an additional genus, but the European species referred to it really belong to *Cidaris*, and the name has been abandoned as a synonym. The specimen described by Vanuxem as *Eocidaris drydenensis* proves to belong to a very different genus. The type is now in the New York State museum at Albany.

North America. In the same way three of the six European Carboniferous genera are peculiar to the Eurasian area. The difference between the two faunas is thus extremely marked, and clearly shows that there was no close connection between the echinoids of the two areas. The absence from Europe of the great family of the *Melonitidæ* is especially striking.

Permian-Jurassic Faunas.

After the Carboniferous system the next fauna of any special value is in the Cretaceous. The Permian of both continents yields a few species, but not sufficient for any definite comparison. The paucity of species in the American Jurassic is also disappointing, as the European echinoids of this age are so exceptionally well known. Descriptions of several species by Professor Clark are now passing through the press and serve to encourage the hope that more may be discovered. As yet, however, the few species known are not sufficient for comparison with the European faunas.

The Cretaceous Faunas.

The Cretaceous system yields much evidence which has been admirably summarized by Professor W. B. Clark in a "Revision of the Cretaceous echinoidea of North America," * issued as a preliminary notice to his forthcoming monograph. In this he enumerates 43 species belonging to 19 genera; in addition to this are the 7 species described by M. Cotteau from Mexico, including representatives of two other genera; some new species found by Professor Clark; and a species of *Linthia* in the museum of the Boston Natural History Society, which, so far as one can judge from the brief diagnosis of *Linthia tumidula*, appears to be new. There are also several more species from South America and the West Indies; the former, however, closely resemble the Mexican species. and the latter are a rather isolated group and may be neglected.† The Cretaceous echinoids of the mainland of North America may therefore be estimated at about 55 species, distributed among 25 genera.‡

If this fauna be examined as a whole it presents a very familiar facies to a European echinologist. Only one genus occurs that is not also found in Europe, while several species are common European forms; but if we separate them into their successive faunas we find one interesting point brought out—*i. e.*, that the members of the earlier faunas agree more closely with the trans-Atlantic species than do those of the upper beds, such as of the Yellow limestone of New Jersey. This is especially well shown by the small fauna described by M. Cotteau from Mexico. This yields six good species, of which three are characteristic of the European lower Cretaceous (Aptien and Urgonien), viz, *Diplopodia malbosi*, *Salenia prestensis*, and *Pseudocidaris saussurei*. The *Enallaster texanus*, moreover, is not unlike some European species, and only the form upon which the late Professor Duncan founded the genus *Lanieria* is quite distinct. The identification of these species rests on the authority of M. Cotteau; his opinion is of especial weight, as the general impression

*Johns Hopkins Univ. Circ. no. 86, 1891.

†The best known of the South American species is the *Enallaster karstein* from Ecuador, described by M. de Loriol. An examination of the type of *Spatangus columbianus*, Lea, now in the museum of the Academy of Natural Sciences in Philadelphia, shows that they are identical, and it must therefore be known as *Enallaster columbianus* (Lea).

‡The following is the list of those recognized in addition to those mentioned in Professor Clark's "Revision:" *Stereocidaris*, *Diplopodia*, *Coptosoma*, *Lanieria*, and *Cardiaster*.

of his work seems to be that he is inclined to limit specific variation within much narrower limits than do many workers on the echinoids. In the larger faunas from the upper Cretaceous, as in that from New Jersey, the whole of the species are peculiar to America, and in most cases the species are quite distinct from their European representatives. The abundance and variety of the species of *Cassidulus* is the most striking feature in this upper Cretaceous fauna, and they are all quite distinct from the European species. Dr. Clark does not admit one species as occurring in the eastern hemisphere (excluding, of course, those described by M. Cotteau), and, so far as I have been able to examine the American collections, I am inclined to agree with him except, possibly, in the case of *Holaster simplex*, Shum. (*H. comanchesi*, Marc.), from the Comanche series of Fort Worth, Texas. There are two good specimens of this species in the American Museum of Natural History, New York. These seem to be indistinguishable from the European *H. lævis* (De Luc), a very variable species in which several well characterized varieties are recognized. The same variations seem to occur in the American forms, and one of the two is our *H. lævis*, var. *trecensis*, the other being *H. lævis*, var. *planus*. Other species from the Comanche series are very different from the European ones—*e. g.*, the *Goniopygus zitteli*, Clark, and *Holectypus planatus*, Roemer. The latter is an interesting species, as its ornamentation rather resembles that of the Jurassic forms. The resurrection of the fifth genital pore is also noteworthy, as it happens in Europe in some allied genera of the same age.

Hence in the American Cretaceous echinoidea we find the relations to their European representatives to indicate that the two faunas were very closely allied in the lowest Cretaceous, but that in later periods of this age the two faunas developed on independent lines. The evidence of this system is of especial value, as in Europe there is practically a complete series of echinoid faunas from the Valangian to the Danian, and thus the difference between these and the upper American faunas cannot be ascribed to differences of age. The New Jersey Middle marl fauna must be not only homotaxial but synchronous with some of the echinoids between the Gault and the upper Chalk.

Eocene and Oligocene Faunas.

A list of the paleogene echinoids from the United States, copied from existing literature, would give but a poor idea of the composition of this fauna or of its affinities. The whole group is in urgent need of revision, and it certainly does not seem a sparse one. Thus, the collection of the American Museum of Natural History includes species of *Sarsella*, *Euspatangus*, and *Breynella*,* none of which have been previously recorded from America. The Smithsonian Institution collections also add the genera *Cidaris* and *Echinarachnius*, and the Academy of Natural Sciences the genus *Monostychia*.

The most striking feature in the echinoid faunas of these two systems is the predominance of the group of flat clypeastroidea, belonging to the genera *Mortonia*, *Periarchus*, *Echinanthus* (Leske non Breynius), *Scutella* and *Echinarachnius*, and of the numerous species of *Cassidulus* and *Pygorhynchus*. The great series of spatangoids found in the European Eocenes are hardly represented. The abundance of the two last genera mentioned is of interest, as they were common forms in the Ameri-

* The *Echinanthus* of MM. de Loriol and Cotteau, but not of Alexander Agassiz and other American authors. See a discussion of this question in a paper, now in the press, by the present writer, on the Maltese echinoids, in the Trans. Roy. Soc. Edinb.

can Cretaceous. It therefore appears that the gradual differentiation of the echinoids of the two areas, which commenced in the Cretaceous, had gone on until the faunas appear strikingly different.

Until a detailed revision of the American Eocene species has been undertaken it is perhaps not advisable to carry the comparison further; but the following notes on the synonyms of a few of the species appear necessary in order to render intelligible the use of some of the above-quoted generic terms. This is especially necessary in the case of the genus *Mortonia* and its allies. This genus was founded by Desor in his "Synopsis des echinides fossiles." The diagnosis was well drawn, obviously from specimens. The only species given was named *M. rogersi*, and a reference given to Dr. Samuel Morton's figure of *Scutella rogersi*. This was unfortunate, as Morton's species is a true clypeastroid, with twinned margins, and belongs to the genus *Echinanthus* (Leske non Breynius). The species which Desor actually described was the *Scutella quinquefaria* of Say. Desor's mistake has led to great confusion, and the names are applied very differently in different American collections. In many cases *Mortonia* is regarded as synonymous with *Periarchus*, but this genus seems worthy of recognition. The type species is *S. altus*, Conrad, but I have not been able to see the type of this species. The common species, *S. pileus-sinensis*, is, however, a good example. The names, therefore, accepted by the writer for this group are:

Mortonia rogersi, Desor non Morton.
Echinanthus quinquefaria (Say).
Periarchus altus (Conrad).

Another thin, flat form, in which a change of nomenclature seems necessary, is the *Sismondia marginalis*, Conrad. The type of this is in the Academy of Natural Sciences, and with its smaller ally, *S. plana*, Conrad, must be transferred to *Monostychia*.

The Miocene Faunas.

The Miocene echinoid fauna of the mainland of America is numerically smaller than that of the Eocene and Oligocene, but it gains considerably in size if the West Indian species be included. Most of the echinoidea described by Ravenel and Tuomey from South Carolina, and referred by them to the Pliocene, must also be referred to the Miocene. On the other hand, some species from the western states usually referred to this system seem to be Pliocene or Pleistocene, and are the common living species; thus some of the specimens labelled *Scutella striatula*, Rem., really belong to the living *Echinarachnius excentricus*. Some of the species referred to the West Indian Miocene seem also to be of later date, such as the *Rhynchopygus guadaloupensis*, Mich., a synonym of *R. caribbaearum*.

Taking, then, the Miocene echinoid fauna with these additions and restrictions, we find it to present a remarkable resemblance to the Miocene echinoids of the Mediterranean basin. This resemblance is established (1) by the presence of several species common to the two faunas—*e. g.*, *Cidaris melitensis*, *Schizaster parkinsoni*, and *Schizaster scellæ;* (2) by the fact that other genera are represented by closely allied species, as in the case of the Maltese and Jamaican species of *Heteroclypeus;* and (3) by the presence in both of genera with a very restricted distribution—*e. g.*, *Agassizia*.

Professor Alexander Agassiz, in his interesting account of the origin and affinities of the long existing West Indian echinoid fauna, has argued that the fact that so

many of the genera are represented by equivalent species on the two sides of Centra America is clear proof of the former connection between the waters of the Antillean and Panamaic regions; but the resemblance between the echinoidea of these two provinces seems to be less close than is that between the Mediterranean and West Indian Miocene. No one species of echinoid is common to both shores of Central America, and the representative species are often more distinct than those of the two Miocene faunas. Hence if Professor Agassiz is justified in his conclusion of the common origin of the Antillean and Panamaic echinoidea, then so also must the Antillean and West Indian Miocene faunas have been derived from a common source. And just as it is considered to prove in the one case a depression of Central America which brought the waters of the Pacific and the Caribbean into connection, so in the other case we must assume a period of elevation which produced a band of shallow sea across the mid-Atlantic. Whether it be assumed that the fauna originated in the Mediterranean and migrated to the West Indies, or vice versa, or whether it developed in some area in the Atlantic now deeply submerged, this shallow water connection is essential.

But there are two explanations that might be proposed that could not involve any such complete opposition to the theory of the permanence of the ocean basins. It might be urged (1) that the common element in the two faunas worked its way around from the one area to the other along the shallow northern shores of the Atlantic; or (2) that the connection was established by the free-swimming larval forms. But we are not without evidence against both of these hypotheses. If we follow the Echinoid fauna of the Helvetian (middle Miocene) from its typical development in Egypt, Malta, Sicily, and Italy toward the north we find at the most northerly area in Brittany that though a considerable series of echinoids remain, the group of species and genera which ally the Mediterranean to the West Indian fauna has completely disappeared. It is just the same in America; the Miocene of South Carolina has yielded none of the same group, which is replaced by species of *Mellita*, *Encope*, *Echinocardium*, etc. This fauna has resemblances to the West Indian, but it is by an element not typically represented in the Mediterranean. Thus, on both sides of the Atlantic the evidence seems fairly conclusive that the migration did not follow the northern route. But we are fortunately not compelled to rely on negative evidence alone. In the Azores, in Madeira, and in the Grand Canary there are Miocene beds which have yielded a small echinoid fauna; in each case the species when determinable are found to be those characteristic of or close allies to the Mediterranean Miocene; in some cases the species are represented by the same varieties. This is, of course, proof only of the original extension of the Mediterranean fauna as far west as the Azores, but this is a very considerable step across the Atlantic; and some West Indian forms, as *Temnechinus*, occur elsewhere only at the Azores, and thus serve to show the completion of the bridge.

In regard to the second hypothesis explaining the connection by the free-swimming larvæ it may be objected that the chances of so delicate an organism as a pluteus surviving the journey across the Atlantic must be somewhat remote, and the species would have no chance of establishing itself unless a number of the plutei arrived simultaneously at a suitable locality. I do not remember that the Challenger surface nets ever collected any plutei of a littoral species in mid-ocean. But here again we are fortunately not left to decide on mere probabilities such as these. Many living echinoidea are now known to be viviparous and to have no free-swimming stage. Now *Schizaster parkinsoni* has in a very marked degree all the

characters of a viviparous form, while *Schizaster scellæ* was probably the same. The occurrence therefore of these species in both the Mediterranean and Antillean faunas is quite sufficient of itself to demonstrate the inadequacy of any explanation based on the passage of the pluteal forms; some of the forms that crossed the Atlantic had an abbreviated development without any pluteal stage.

The Pliocene Faunas.

In the Pliocene period the echinoidea are scarcer and less well known than in the Miocene, and now that most of the species described by Ravenel and Tuomey have been transferred to the earlier division no very definite fauna is left. In fact on the mainland there are only a few recent species, such as *Mellita sexforis* from Carolina and *Echinarachnius excentricus* (syn. *Scutella striatula*, Rem. non Marc. de Serres) from the Pacific slope. The collections of the Academy of Natural Sciences of Philadelphia and the Smithsonian Institution also contain some specimens of the living *Echinanthus reticulatus*, Linn. sp. (*sensu* Lovén; the *Echinanthus*—or *Clypeaster*—*rosaceus*, Auct.) from Coloosahatchie, Florida. These, however, seem to be all recent species, whereas in the European Pliocene but few living species are represented. The few echinoids from beds of this age in the United States have no particular affinities with the European ones.

There are, however, two species of echinoidea from deposits in the West Indies that may be referable to this age, and which cannot be overlooked, as they have important bearing on questions of physical geography. They are *Cystechinus crassus*, Greg., and *Asterostoma*, n. sp., both from the Radiolarian marls of Barbados. The geological bearing of the discovery of such a typically deep-sea genus as *Cystechinus* was referred to at the time of its description, but it has gained considerably in interest by the recent work of Professor Agassiz. At the time of the discovery of the Barbados specimen the genus was only known from the Antarctic and the China sea. It has now, however, been dredged by Professor Agassiz in deep water off the western coast of Central America, but the species is so far known only by the few remarks made about it by Professor Agassiz in his preliminary report on the results of the cruise; yet as far as we can judge from these it is closely allied. The species of *Asterostoma* is of interest from the light it throws on the age of the beds in Cuba, from which the original specimens of this genus were derived, from their resemblance to *Echinocorys* (*Ananchytes*). M. Cotteau referred them to the Cretaceous, but the discovery of this Barbadian specimen renders it highly probable that they should be transferred to the upper Cenozoic.

The paucity of American Pliocene echinoidea is to be regretted, as those of this age in Europe have been in most cases carefully collected and monographed. With the few Pliocene echinoids from America they have nothing in common; but as the writer has pointed out in a recent "Revision of the British fossil Cenozoic echinoidea," those of the English Crag have many affinities with the existing fauna of the West Indies. The Crag echinoids number 22 species, and may be divided into two groups: (1) the common northern European forms, or species closely allied to these; and (2) a group of genera represented together elsewhere only in the West Indian area. Thus, in the English Crag there are species of *Temnechinus*, *Agassizia*, *Rhynchopygus*, and *Echinolampas*, of which the nearest allies are Caribbean species. Now, these are all either tropical or littoral forms, and it is of interest to note that they do not occur elsewhere among the European Pliocene deposits. The fauna which agrees best with that of the English Crag

(excluding the few patches of Pliocene sand in northern France) is that of Belgium. This, however, contains but two British species, though as a rule the species are allied; the main difference consists in the presence of some Mediterranean species and the absence of the four genera of the western group. The richest of the Belgian beds is the Diestian, which is older than our Coralline Crag. This, therefore, suggests that the "western group," as we may call the second element in the Crag fauna, did not reach Europe until post-Diestian times, and thus did not penetrate so far east as Belgium.

In this case the same suggestions as to the possible northern migration or the floating across of the larvæ might be made, and there is less evidence on the subject than in the Miocene. The only well-known species of *Temnechinus* from the Crag (*T. woodi*, Ag.) was probably viviparous, and it may be that the West Indian species is so also; otherwise there is no evidence to directly disprove this second hypothesis. As there is no known European Pliocene fauna north of the Crag, and as the Pliocene series from the American mainland is also very scanty, there is no such means of disproving the northern extension of these tropical or subtropical forms; but had this happened we might have expected a much greater mingling of the faunas of different zones of latitude than has happened. The echinoidea of the European shore agree more closely with those of the corresponding isotherms on the American side than with the faunas north and south of them. The presence of *Temnechinus maculatus* at the Azores as well as in the West Indies also further suggests that the connection was established somewhere in the mid-Atlantic.

Summary of Conclusions.

A brief comparison of the successive echinoid faunas of Europe and America has thus been attempted, and it may be advisable briefly to summarize the conclusions arrived at.

In the Carboniferous period there was an almost complete difference between the two faunas, whereas in the succeeding Urgonien and Aptien the two faunas are almost identical. But the Cretaceous period was marked by a gradual differentiation; species ceased to be common to the two areas, and the representative forms became more distinct. In the Eocene and Oligocene the same independent evolution seems to have gone on; the American fauna was rich in species of *Cassidulus* and *Pygorhynchus*, genera also common in the Cretaceous beds of the same continent, and the faunas were more distinct than were the Cretaceous. During the Miocene there was again a change: a fresh connection was established that enabled the echinoidea of corresponding latitudes in the new and the old worlds to commingle; and later still, in the Pliocene, there is evidence to show the introduction into the European area of some American echinoids. The possibilities of this connection across the Atlantic by free-swimming larvæ or by the adults having worked around the northern margin have been examined and evidence adduced against them, and one case is quoted in which the dissimilarities of fauna cannot be explained as due to difference of age.

It is therefore urged that the comparison of the succession of the echinoid faunas of Europe and America present a series of phenomena wholly incompatible with the theory of the permanence of the great ocean basins.

Remarks were made upon the topic of the paper by Mr. L. C. Johnson.

The next paper was on—

THE MISSOURI COAL MEASURES AND THE CONDITIONS OF THEIR DEPOSITION.

BY ARTHUR WINSLOW.

[*Abstract.*]

The Distribution of the Carboniferous Rocks.

The Ozark Uplift.

The Carboniferous rocks of Missouri flank the northern and western sides of that great quaquaversal arch which has been so appropriately termed by Broadhead

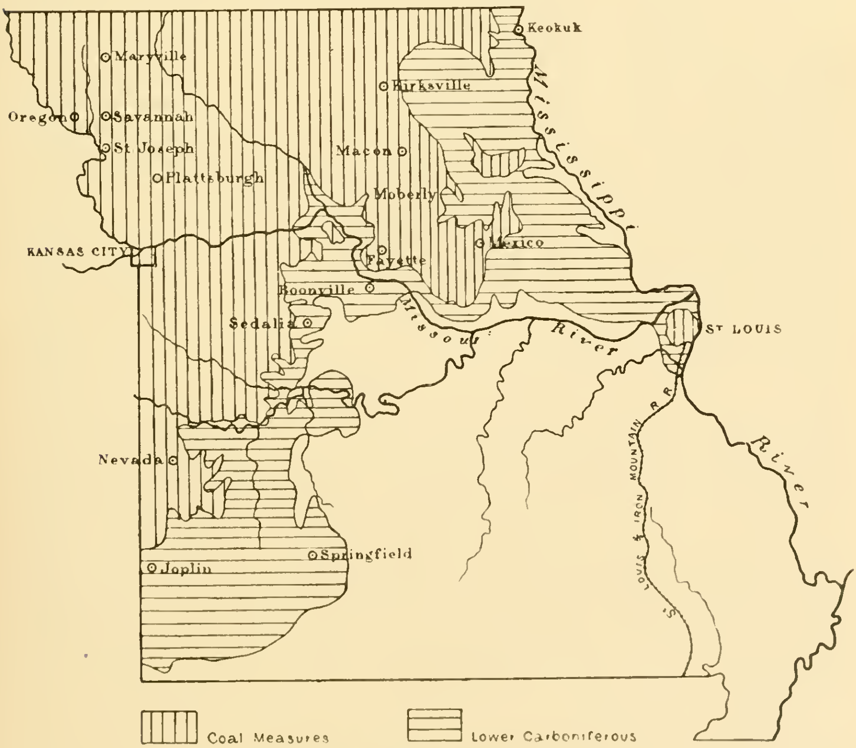


Figure 25—*Sketch Map of Missouri.*

the Ozark uplift.* This dome-like protrusion is exhibited over an area of not less than 15,000 square miles in the central portion of the state, south of the Missouri river. Its location is represented in a general way on the small map forming figure 25 by the broad white space west of the Iron Mountain railway. It includes topographically the most elevated portion of the state, the plateau mass called the Ozark mountains being within its bounds. The geological formations represented are chiefly the Lower Silurian; these occupying the whole central area as massive sheets of magnesian limestone, with intercalated sandstones. Near the center they lie generally in a nearly horizontal position, but toward the margin of the uplift they slope off radially under the overlying formations.

Age of the Upheaval.

This upheaval was, apparently, thought by Broadhead † to have begun just before the close of the earlier Carboniferous, and to have continued until after this period. The evidence of this would seem, however, far from conclusive. It consists in the existence of outlying patches of lower Carboniferous rocks within the area of the uplift and beyond the margin of the main body of the formation. These outliers are not abundant, and the most remote mentioned by Broadhead is an occurrence of Chouteau rocks in Wright county, not over thirty miles from the margin of the lower Carboniferous area. During the past field season discoveries of lower Carboniferous fossils farther in the interior have been made by Mr. J. D. Robertson, assistant of the Missouri geological survey. They were found a few miles southeast of Rolla, in Phelps county, and also near the northeastern corner of Douglas county. The fossils were in a few loose fragments of chert scattered over the surface; no rock being found *in situ* carrying such organic remains. These occurrences would seem to indicate the former presence of the earlier Carboniferous sea over these localities, or the submergence of the area, at that time. On the other hand, however, the scarcity of these Carboniferous rocks and the total absence of rocks intervening between these and the Lower Silurian beds, within the main area of the uplift, goes, so far as negative evidence can go, to prove that the intervening beds were never deposited entirely over it; that the lower Carboniferous beds reached up on its sides perhaps no farther than the limits of the outliers referred to would indicate; and that these latter, over the Ozark area, were of very limited thickness, such as were subsequently readily removed by erosion. The last condition is in harmony with the hypothesis that these lower Carboniferous beds of the Ozark region were deposited during the earlier part of that period, and that their accumulation was arrested by the emergence of the area during early Carboniferous time while the upper beds were still in process of formation in surrounding zones.

Of movement and extensive uprising after the deposition of the lower Carboniferous rocks we have abundant evidence. This is shown by the unconformity which exists between the lower Carboniferous limestones and the overlying Coal Measure rocks. This unconformity has been so often described by Swallow,‡ Shumard,§ Broadhead,‖ White,¶ and others as to call for no special demonstration or reference

* The Geological History of the Ozark Uplift, by G. C. Broadhead: American Geologist, vol. vii, 1889, pp. 6–13.

† Op. cit., p. 12.

‡ Report Mo. Geol. Survey, 1855.

§ Report Mo. Geol. Survey, 1871.

‖ Report Mo. Geol. Survey, 1873 and 1874.

¶ Report Iowa Geol. Survey, 1867.

here. It is exhibited, in brief, by tilted lower Carboniferous strata, in places underoverlying horizontal Coal Measure beds, and also by easily recognized pre-Coal Measure erosion. The latter is shown by the existence of Coal Measure rocks deposited in these previously eroded valleys, and also by extensive accumulations of the detritus of the lower Carboniferous rocks in such depressions; these phenomena being frequently observable over the marginal area of the Coal Measures. Just how extensive this Carboniferous elevation was cannot exactly be stated at present. There is evidence that, in places, for some fifty miles in from the margin of the Coal Measures the lower Carboniferous rocks were brought to the surface and eroded, and it is probable that this extended much farther. It is possible that the lower Carboniferous floor underlying the whole Coal Measure area of Missouri was raised above water level and subjected to erosion. However this may be, we are safe in stating that the Coal Measures were laid down upon an uneven surface, which, at least over the marginal portion, was decidedly rough, broken by hills and ravines as a result of erosion. The probable general condition is represented in the accompanying figure 26.

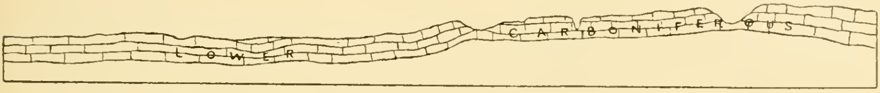


FIGURE 26—*Ideal Section through the Ozark Uplift*

Representing the probable condition of the floor upon which the Coal Measures were laid down.

Of still farther movement and renewed submergence before the Coal Measure period, the presence of the Coal Measure rocks upon the uptilted lower Carboniferous strata, or in the channels eroded in the latter, yields ample proof. Just what the extent of this submergence was and what were consequently the original limits of the Coal Measures is another question. Of their original extension over the Ozark area we have little or no evidence, other than the fact that the thickness of the Coal Measures in the northwestern part of the state is very great, such that if the upper rocks there once extended to the present eastern limits of that formation, they must have reached far beyond these limits and probably over the Ozark region. That the upper Coal Measure rocks may never have extended to the present eastern limits is, however, shown in the following pages; therefore the former submergence of the Ozarks is not necessary in order to explain the great thickness of the Coal Measure strata.

In support of the idea that the present marginal limits are near the original ones, we have, on the other hand, the fact that the present marginal beds are distinctively marginal deposits, and further, we have the negative evidence that no Coal Measure strata, which may be strictly classed as outliers, occur far away from the general margin of the formation, well within the Ozark area.*

* In apparent negation of this statement, recent examinations, by the state geological survey, have shown the presence of those peculiar deposits of coal known as "coal pockets" in the very heart of the Ozark region, in Douglas, Dent, Phelps, and Crawford counties. These, however, by no means call for an original extension of the whole formation to the extent of including them. It is true that they are probably of Coal Measure age, but the most satisfactory theory of their formation is that they were accumulated in inland basins, or cavities, formed by previous erosion or solution of limestone, and were not connected with the main body of the Coal Measures. The fact that they are frequently found in and surrounded by Lower Silurian rocks goes far toward proving that the later intervening rocks were either never deposited where such coal pockets are found or, if deposited, that they were uplifted and entirely eroded before the deposition of the Coal Measure strata began.

Summarizing, therefore, we are inclined to maintain the view that the movements which *originated* this uplift were in Silurian times, even Lower Silurian, and were consequent upon the deposition of the great mass of Lower Silurian strata in the sea surrounding the Archean archipelago. Further, the absence, in places, of Upper Silurian and of Devonian beds under the lower Carboniferous strata, which lap upon the sides of this Lower Silurian dome, shows that this early and first upheaval was extensive, and that large areas were lifted at that time above water level to be submerged later in the Carboniferous seas for the deposition of the lower Carboniferous limestone, the limits of which are outlined on the map forming figure 25.* The pre-Carboniferous submergence was sufficient to allow the waters to reach well up over the sides of the Ozark area and possibly great enough to place it entirely beneath water level. Uplifting began again, however, soon after this; so that, at most, only a thin deposit of lower Carboniferous rocks was formed over the Ozark dome, which was subsequently entirely eroded. This uprising continued, perhaps intermittently, until after the end of the earlier Carboniferous period, when the rocks of that formation were brought above the waters and were subjected to extensive subaërial erosion. At or near the beginning of the Coal Measure period, submergence began again and continued until, and probably beyond, the close of that period. The Ozark area remained above the waters during this submergence, however, and has continued so ever since; the present eastern limits of the Coal Measures being approximately the same as originally outlined.

The Phenomena of the Coal Measures.

Distribution and Hypsometry.

The Coal Measures of Missouri cover the western and northwestern portion of the state, occupying an area of some 23,000 square miles.† The general outline is familiar to many, but, for purposes of ready reference, it is given on the small sketch map forming figure 25. The altitude of the surface within this area varies from about 600 feet to nearly 1,300 feet. Along the marginal lines of the Coal Measures, from northeast to southwest, the following are the approximate altitudes at successive points on the summits between drainage channels: Kirksville, 975; Macon, 886; Mexico, 798; Moberly, 867; Fayette, 800; Boonville, 750; Sedalia, 907; Clinton, 807; Nevada, 870; Joplin, 1,018.

In the interior, along the western border of the state, the following are the altitudes at successive points located similarly topographically: Kansas City, about 950; Leavenworth, about 1,000; Plattsburg, 1,000; St. Joseph, about 1,050; Savannah, 1,100; Oregon, 1,100; Maryville, 1,200; Watson, 1,100.

Along the margin the Coal Measures may be considered to thin to a feather edge, while in the extreme northwestern corner of the state they have an aggregate thickness of perhaps 2,000 feet, and consist of probably more than 200 strata.

*In a paper entitled "The Missouri River," published in American Geologist, September, 1889, Professor Broadhead states, on page 154, that the Ozark plateau "began to rise just after the Canadian. . . . From the Canadian to the beginning of the lower Carboniferous it was dry land. It then became sufficiently depressed to receive limestone deposits near its outer margin during the early Subcarboniferous, a few beds of the later Chouteau, and early Burlington." These statements lead one to the conclusion that he has abandoned the belief of the Carboniferous age of the uplift referred to on page 110, and that the writer's opinions, so far expressed, are substantially in accordance with those held by Professor Broadhead.

†Report Mo. Geol. Survey, 1872, part ii, p. 5.

On the basis of the figures above given we have an elevation of about 900 feet for the floor of the Coal Measures at the margin near Sedalia, and in the extreme northwest the position of the floor is about 700 feet below sea level. Consequently the present slope of this floor is 1,600 feet in a distance of some 150 miles, which is equivalent to about 10 feet per mile, or about one-tenth of one degree of slope, which is almost horizontal. The elevation of the surface of Maryville is about 1,200 feet; so that the thickness of the Coal Measure rocks there found *above the level of Sedalia* is only about 300 feet; thus the regional elevation which finally lifted the Coal Measures above the water level was not necessarily much greater in the interior than along the margin.

Lithology and Stratigraphy.

The rocks of the Coal Measures consist almost wholly of sandstones, shales, limestones, and coals.

The sandstones are of white, drab, yellow and reddish colors, are generally fine grained and friable, and are often filled with specks of carbon and with impressions of leaves and stems, especially along the stratification plains; mica is almost always present. The sandstones are most abundant and prominent in the eastern and marginal area of the Coal Measures, and they there constitute a considerable portion of the section. In the interior or central area they are not prominent members, though arenaceous shale is abundant, and it is frequently difficult to say whether such material should properly be classed as a shale or as a sandstone.

The shales are argillaceous, bituminous, arenaceous, or calcareous, and frequently grade by almost imperceptible degrees into sandstones or limestones; they are of black, drab, gray and red colors. The shales preponderate by far over either of the other classes of rock, are widely distributed, and are about equally prominent in all sections of the Coal Measures.

The limestones are sometimes in massive beds, three and even more feet in thickness, are occasionally concretionary and in nodular forms, are sometimes laminated with uneven bedding planes, but are almost always of a fine compact texture; they are of drab color, and are readily distinguished from the white, coarse-grained, semi-crystalline limestone of the lower Carboniferous. The limestones are least abundant over the extreme marginal area, and become more frequent and thicker toward the interior; in the northwestern portion of the state they occur in beds aggregating twenty or more feet in thickness. Lime is here very abundantly represented in all the rocks; many of the shales, even the black bituminous layers, being decidedly calcareous. As with the shales and sandstones, so with the shales and limestones, it is often impossible to class a rock positively as a limestone or as a shale.

The coals are all bituminous, with the exception of certain local deposits which approach cannel coal. The beds range in thickness from one inch to about five feet. They are generally soft and pyritiferous, with selenite almost always present in thin scales along the joint planes. They are almost invariably underlain by clay, which sometimes contains stigmaria casts. They are generally immediately overlain by black shales, frequently fissile, or by a gray or drab clay shale. In this shale leaf impressions are found in places, but the localities are few where such are abundant. Sometimes sandstone rests directly upon the coal, or a limestone cap-rock is barely separated from it by a few inches of clay or shale, but such instances are exceptional. The coal beds are most abundant and are thickest over the marginal

portion of the Coal Measures, where they occur near the surface and where they have been principally and most extensively operated up to the present time. They seem here, however, to be more irregular in character and distribution than in the interior, so far as one can judge from the limited developments which have been made in the deep-seated coals of the interior region.

Among the most noticeable features of the stratigraphy of these Coal Measures is the variability of details. The strata are characteristically non-persistent, as regards thickness as well as material. Beds of coal thin out and disappear; beds of shale pass into sandstone or grade into limestone, as the case may be; limestone beds fluctuate greatly in thickness, or may be present or absent in not widely separated localities. These conditions are particularly prevalent over the marginal area, among what has been considered the lower Coal Measure rocks. Swallow,* Norwood,† and Broadhead‡ all refer to such variations of sections, and they are encountered in mining operations, often to an embarrassing extent. Of most conspicuously irregular distribution are the sandstones of the marginal area. These sandstones may be divided into two classes: First, there are the regularly interstratified beds, ranging from two to ten or more feet in thickness, which, though less persistent than the other beds, can yet be recognized clearly as interstratified members over considerable areas. Second, there are the great massive deposits of sandstone, sometimes exposed to a thickness of 50 or 60 feet without displaying any bedding planes. These may be connected with the thinner interstratified beds, but where they attain their characteristic development they cannot be classed as interstratified beds of the Coal Measures, but apparently are deposits filling channels which were eroded in the Coal Measure strata presumably during the Coal Measure period.§

The fauna of the Coal Measure rocks indicates the previous existence over the marginal area, in what have been termed the lower Coal Measures rocks, of brackish and shallow waters, while in the interior, among the rocks designated upper Coal Measures, marine forms are more abundant. There is nothing at all pronounced in the fauna which would call for great priority of deposition of the rocks of the marginal area over those of the interior.

The Conditions of Deposition.

From a consideration of the facts and conclusions presented in the preceding pages, it appears that the following conditions must be satisfied by any interpretation of the process of deposition which may be offered:

1. That the marginal conditions were generally those of brackish water and favorable for the formation of the coal beds.

2. That marine and deep-water conditions were more frequent over the central area, permitting the deposition of thick beds of limestone.

---

* Report Mo. Geol. Sur., 1855, p. 87.

† Report Mo. Geol. Sur., 1873–'74, pp. 200–215.

‡ Report Mo. Geol. Sur., 1872, part ii, p. 166, and elsewhere.

§ These channel deposits are, in places, a mile or more wide and apparently 200 or more feet thick; they limit sharply the coal beds and the other regularly deposited strata. Their distribution is being carefully studied by the state geological survey, and they promise to prove a most valuable and interesting subject of study. Their exact age is not at present determined, and it is possible that they may ultimately be assigned to the Permian or even to a later period. On the other hand, if they can be traced beyond the limits of the Coal Measures, it is probable that at least a part of the sandstone which has been classed as the Ferruginous sandstone of pre-Coal Measure age really belongs to this formation.

3. That during the process of deposition the strata from the base to the top of the Coal Measures were, at intervals, at or near the surface of the water, permitting the growth of the coal flora and the accumulation of coal.

4. That at least some of the strata were deposited in an exactly horizontal position.

5. That the margin of the Coal Measures never extended much beyond the limits at present recognized, and that the strata of the interior never reached over those of the margin.

According to views hitherto presented, the Coal Measures of Missouri have been separated into upper, middle, and lower divisions, respectively 1,317, 324, and 250 feet thick,* all having a slight dip a little north of west. The prevalent opinion concerning these divisions, as well as those of the contiguous Iowa Coal Measures, is that they underlie each other successively, and that, should the strata of the upper Coal Measures in the northwestern part of the state be penetrated by a shaft, the members of the middle and lower Coal Measures would be successively encountered. The reservation is generally made, however, that some of the beds will probably thin out, disappear, or be replaced by others, so that exactly the same succession of strata cannot be expected, though whatever may be included under the indefinitely applied term "formation" is considered to be continuous. The adjoining figure 27 represents in a general way the implied and commonly conceived positions and relations of these divisions of the Coal Measures.

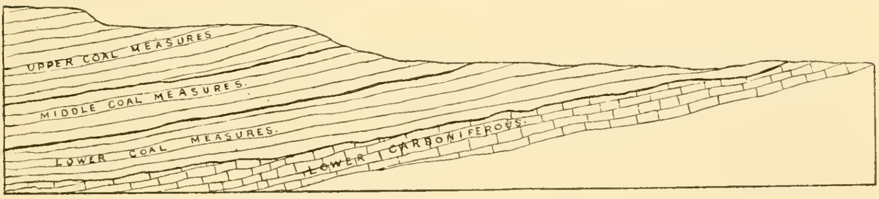


FIGURE 27—*Ideal Section of the Coal Measures of Missouri and Iowa.*

The nature of some of the Coal Measure strata demands horizontality of position at time of deposition, and as, according to the above representation, the strata are parallel with each other, they must, on this interpretation, all have been deposited as horizontal layers and subsequently tilted simultaneously into the present position. Further, the existence of coal beds near the base of this formation shows that even the lowermost strata were accumulated near the surface, and hence, to produce the conditions generally pictured, would require a regional subsidence of about 2,000 feet, equal in rate and amount over the whole area, with which the process of deposition kept pace equally and exactly over every portion. A restoration to a horizontal position of these strata is represented in figure 28, and it is there apparent at a glance that, following out this supposition, the portions of at least the upper part of the formation represented could be only small remnants of the whole, and that, with the indicated thicknesses, they must once have spread over the whole Ozark region, as well as over the area of lower rocks in northern Iowa. We cannot believe such extension possible without at least some remnant of these rocks being left over territory where they are now never found, as already stated in connection with the

* Report Mo. Geol. Survey, 1872, part ii, p. 6.

discussion of the age and history of the Ozark uplift. The hypothesis is contrary to the authoritative and generally accepted views concerning the original limits of the Coal Measures both in Missouri and Iowa. Such representation of the relation and positions of the Coal Measure strata leading to conclusions contrary to accepted views, it behooves us to attempt a presentation of the results and of the process of

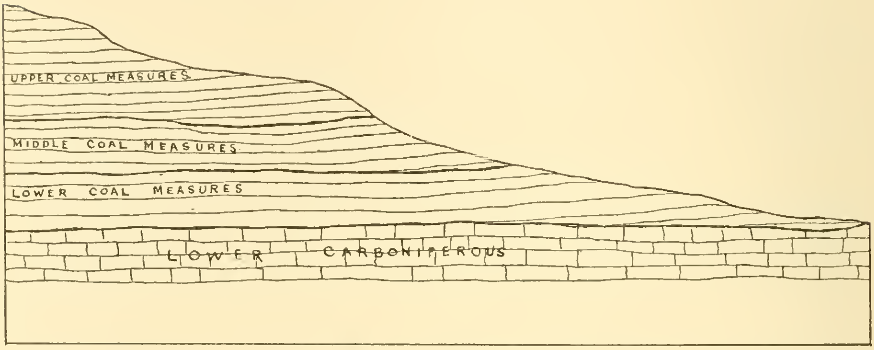


Figure 28—*Ideal Section of the Coal Measures of Missouri and Iowa restored to horizontal Attitude.*

deposition which will be in harmony with the observed facts and well substantiated conclusions.

Starting with the indisputable fact, as proved by deep drilling and shafting in the western portion of the state, that at or very near the base of the Coal Measures there are strata of shallow-water origin, we must allow that the lower part of the floor was at the beginning of deposition near the surface. We will assume next that submergence soon began over the central area of the Coal Measures, and that, as represented in figure 29, the margin of the early Coal Measures sea or swamp *B* was well

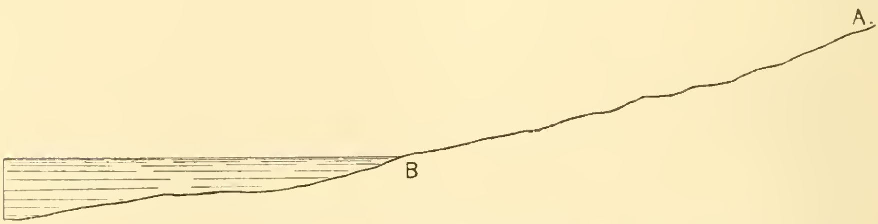


Figure 29—*Ideal Representation of the Beginning of Coal Measure Deposition*

within the present limits *A* of the deposits. As soon as this area became submerged deposition over it would begin; but, as all material is derived from or beyond the margin, the accumulation during any stated period would be thickest along the margin and would thin thence gradually toward the interior, the character of the material changing at the same time. The marginal area would thus be the first to become a shallow-water area suitable for the formation and accumulation of coal. As the basin became gradually filled with sediment from the margin toward the interior the coal swamp would slowly creep out horizontally, until it covered the whole surface in a continuous sheet, apparently slightly unconformable with the

underlying strata which were accumulated in slightly inclined positions. Figure 30 represents the resulting conditions, provided deposition is continued and subsidence is arrested. The number of deposits cannot be taken to represent, strictly speaking, so many individual and separated strata, as each one may be made up of a varying number of layers of different materials; they simply indicate the limits reached by the deposits in successive intervals of time. The apparent dip and the consequent unconformity of the coal layer *C C* upon these underlying strata is also much

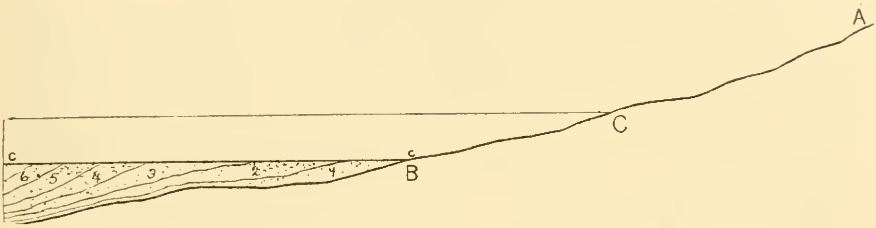


FIGURE 30—*Ideal Representation of a complete Cycle of Deposition of Coal Measures, and of their Mode of Accumulation.*

exaggerated by the excessive vertical scale. If reduced to the natural scale, neither the dip nor the unconformity at any one point would be perceptible.

The natural results of such a growth of sediment is that a coal bed should be thicker near the margin, where its accumulation began, than in the interior, and the thickness of the bed at any one point will depend upon the length of time during which subsidence was arrested and the accumulation was allowed to go on. The coal bed may expand over the whole area, as is represented in figure 30, and may there accumulate through a thickness of several feet, and then be cut short by a submergence to the point *C*, when another cycle of deposition will begin similar to the first.

Changes in the amount and character of the sediment supplied at any time during such a cycle would cause corresponding changes in the thickness and character of the strata. A rapid, continuous, or frequently recurring subsidence would prevent the accumulation of coal, or would allow of its formation only over narrow marginal areas. A subsidence after the coal bed had expanded over a half or other fraction of the submerged area would fix a limit to that individual bed at such point, and it would be buried beneath the strata of the succeeding cycle of deposition. A varying rate of subsidence over different areas would also affect the character of the deposits. Where the rate was greatest, deep-water or marine conditions would be more prevalent, and where the rate was slow shallow-water conditions would prevail generally and coal beds would be more frequent. If the rate of subsidence over the interior were constantly greater than that over the marginal area the first formed and lowest beds would gradually acquire a westerly dip, while the upper beds were horizontal, and the aggregate thickness of the deposits would be increased toward the interior, although the thickness of an individual stratum, or of a heterogeneous deposit formed during any interval of time given, would be thinner, proceeding from margin to interior. If subsidence were arrested along the margin and continued in the interior, the deposits would thin to a feather edge along this margin. On the other hand, if there were elevation along the margin and subsidence in the interior, the succeeding deposits would thin out within what were previously the marginal

limits and would abut against the underlying strata. If subsidence were arrested in the interior and continued over the margin, coal beds might be formed in the interior which were not represented over the margin.

Figure 31 is an ideal representation of what would result with a certain sequence of events of the character suggested. At *B* is a coal bed, originally horizontal, which extended entirely across a submerged area before subsidence set in again. At *C* is another bed which extended, however, only a short distance before being submerged. At *A* is a third coal bed which had a longer period of growth than *C*, but which was also cut off by a sinking of the strata. From the divergence of the lines *A* and *B* it is evident that the rate of subsidence was greater over the interior than at the margin. Before the deposition of the bed *B* the margin at *A* was elevated and the depression in the interior continued, and these opposite movements were kept up during the periods of accumulation of the strata *E* and *F* and of those intervening between these. The next section (figure 32) represents the same group of beds after they have been elevated above the water, so that the upper beds are elevated some 400 feet above the extreme margin. It is, of course, impossible to represent in any such diagram the infinitely complex association and the varied succession of strata which resulted from all the combinations of conditions which probably prevailed during the deposition of the Missouri Coal Measures, but, always allowing for the great distortion of thicknesses and of angles of dip and slope, this diagram will probably suggest all of these.

The careful study of the above outlined hypothesis and of the last diagram will show that it is calculated to satisfy fully all of the conditions enumerated on page 114. Such a study will reveal:

a. How a moderate amount of erosion might suffice to produce the present limitations of the upper strata.

b. Why coal beds are more abundant over the marginal area.

c. Why the interval between any two strata may be very different at different points.

d. Why a columnar section, constructed from outcrop measurements of successively exposed strata from margin to topmost layer, will not represent the succession of rocks in such a section as *O O*, in figure 7.

e. Why a coal bed may at different points immediately overlie strata which are widely separated from each other in some exposed section, and hence why two separated outcrops of the same coal bed may easily be mistaken for outcrops of two different beds.

f. Why the strata cropping out along the margin are not necessarily the lowest beds, even though they dip toward the interior, and why beds encountered at the base by drilling in the interior may be of earlier age than these marginal beds.

g. That the arenaceous character of the marginal deposits is an essential attribute of their location and not one of their age, and that sandstone, shale, or limestone may be prevalent among the upper or lower beds of the Coal Measures according as they were marginal, shallow-water, or marine portions of the deposit.

Something like a true section of these Coal Measure strata may ultimately be constructed by the present state survey after all the many sections and records obtainable have been studied and correlated. Until then we must proceed with extreme caution, with the anticipation that all the intricacies of deposition which the conditions herein referred to call for may exist and will have to be traced.

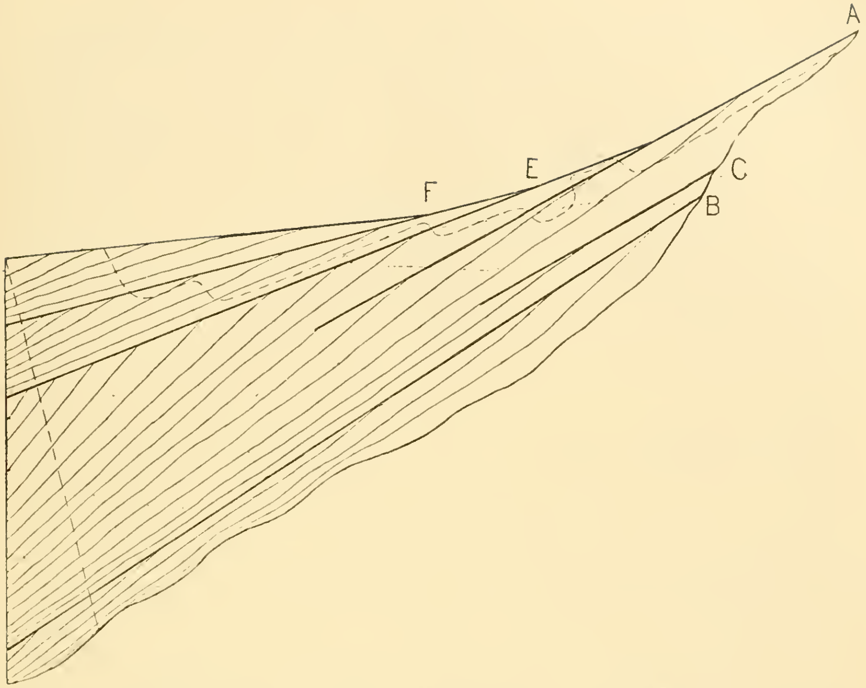


FIGURE 31—*Ideal Illustration of the Accumulation of the Coal Measures.*

Representing the results of successive cycles of deposition. Vertical scale greatly exaggerated.

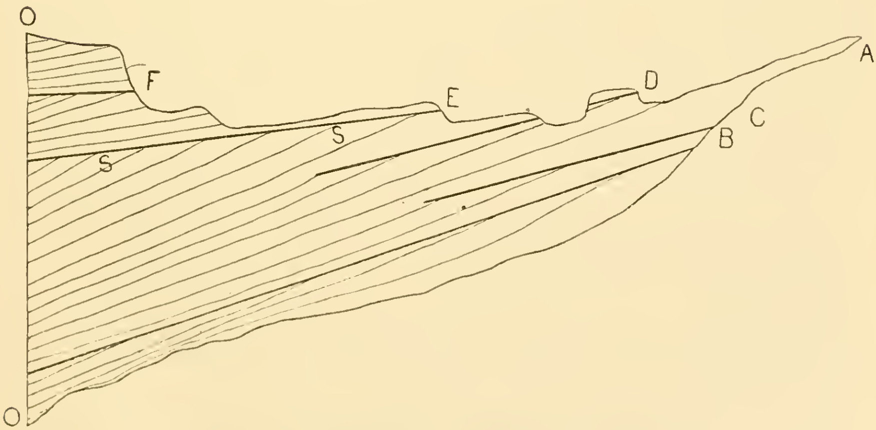


FIGURE 32—*Ideal Representation of the Missouri Coal Measures.*

From the actual connection between the Missouri coal fields and those of Iowa, Kansas, and Arkansas one would expect to find similar conditions there, and such indeed is the case. Hall,* in describing the Iowa Coal Measures, says: "We must, therefore, be prepared to find ultimately that the Coal Measures, or at least the productive portions of that formation, thin out in great part or entirely in that direction [toward the interior], while the calcareous portions, which are of marine origin, will be found increasing in force." C. A. White † describes the shallow seas of the Coal Measure period as ending well south of the northern line of the state, and refers to the thickening of the formations toward the center from the border,‡ though he is of the opinion that "the coal-producing strata passed entirely beneath the unproductive ones and do not disappear by thinning out as they do in the opposite directions." § Keyes, in writing of the stratigraphy of the Iowa Coal Measures, described the gradation of shales into sandstones on the one hand and into coal on the other. ‖ The coals, he says, are not in continuous layers over the whole area, but in lenticular patches; ¶ and he estimates them of little value for general correlation.

Similar conclusions may also be drawn from the phenomena of neighboring regions. Thus, Newberry, in describing the Coal Measures of Ohio, states that the upper coals never reached so far as the lower ones, as they have been found only in the center of the basin.** He also refers to the great variation of the intervals between coal seams, and in general terms suggests an unequal sinking of the area in explanation. He also described the coal basins there as of limited extent.†† Orton, in writing later of the Ohio coals, states his opinion that the later coal beds never extended over the outside margins of the earlier swamps, and in explanation he suggests a simultaneous rise of the border and a sinking of the interior.‡‡ All coals below the Freeport, and others, he states, were apparently formed as marginal swamps, and, with reference to the general question, he concludes: "If we see reason to believe that these lower seams originated in marginal swamps, with the sea near at hand, then, of course, we abandon the older view that the coal seams extend indefinitely toward the center of the basin. . . . We should expect to find the interior of the basin filled with *terrain mort*." §§

I. C. White, in his recent description of the stratigraphy of the bituminous coal fields of Pennsylvania, Ohio and West Virginia, states that though valuable coal beds are found in the central portion of the trough, it is true, as a general law, that the coal beds of this series (the lower Coal Measures) are thicker and better and more numerous around the margins of the Appalachian field than toward the center, and he states the same concerning the coals of the Pottsville conglomerate. ‖‖

As early as 1872, J. J. Stevenson, in describing the upper Coal Measures of Ohio, Pennsylvania and West Virginia, referred to the disappearance of strata and the

* Report Iowa Geol. Survey, 1858, part 1, page 135.

† Report Iowa Geol. Survey, 1870, vol. 1, page 227.

‡ Op. cit., p. 250.

§ Op. cit., p. 259.

‖ The Stratigraphy of the Iowa Coal Measures: Bull. Geol. Soc. Am., vol. 2, p. 282.

¶ Op. cit., p 284

** Report Ohio Geol. Survey, Geology, vol. 2, 1874, p. 117.

†† Op. cit., p. 166.

‡‡ Report Geol. Survey of Ohio, 1884, Economic Geology, vol. 5, p. 135.

§§ Op. cit., p. 137.

‖‖ Bulletin U. S. Geological Survey, no. 65, 1891, pp. 100, 181.

merging of one into the other with a consequent coalescence and bifurcation of coal beds.* Again, in 1874, in a paper on the parallelism of coal beds, he adduced many instances of coal beds dividing, and concluded that all the coals of the upper Coal Measures are offshoots from the Pittsburgh coal seam, formed by regular subsidence and shorter intervals of repose, deltas and marshes being developed during repose, yielding the minor coal beds, while during subsidence the marsh advanced up the sides of the trough, forming the Pittsburgh bed.† Four years later, in a chapter on the structure of coal beds forming part of a report on the Ligonier valley, he again stated the same conclusion, after introducing additional data.‡

The inference from these references is plain that the explanation of the process of deposition in Missouri applies to other areas, and is doubtless of wide applicability, at least so far as Coal Measure deposits are concerned, and perhaps with regard to other formations.

The next succeeding paper was read by title:

THE WELLS CREEK BASIN AND UPLIFT IN STEWART AND HOUSTON COUNTIES, TENNESSEE.

BY JAMES M. SAFFORD.

The following paper was then read, the objects described being exhibited:

THE PELVIS OF A *MEGALONYX* AND OTHER BONES FROM BIG BONE CAVE, TENNESSEE.

BY JAMES M. SAFFORD.

Contents.

INTRODUCTION.

In September, 1886, Mr. A. J. Denton, of Henderson, Tennessee, brought a box of bones to Nashville and left them for my examination. A letter was received from Mr. Denton concerning them, from which I take the following extracts:

"They were found in a cave in the Cumberland mountains, Van Buren county, Tennessee, * * * the cave in which were found some very large bones about fifty or sixty years ago, and which are now in a museum in Philadelphia. * * * The bones left for you were discovered in 1884 by a laborer who was digging the so-called guano (bat manure) in the cave. * * * They were covered to a depth of about three feet, and were lying in such position as to show they had never been disturbed. The head, vertebræ and hip bones were in the position which they would necessarily have

*The Upper Coal Measures West of the Alleghany Mountains: Trans. Amer. Lyceum of Nat. Hist. of New York, vol. x, 1872, pp. 226–252.

†On the Alleged Parallelism of Coal Beds: Proc. Am. Philosophical Soc., vol. xiv, 1874, pp. 283–295.

‡2nd Geol. Survey of Pa., K K K, 1878, pp. 283–303.

after the decay of the animal, showing it to have been about eight or nine feet long. They created considerable interest among the people in the neighborhood, but no one could give even a reasonable conjecture as to the kind of animal. The other bones (those of the skeleton not in the box) were decayed or crumbled immediately after being exposed to the air."

The bones were found to be those of *Megalonyx*. They were purchased from Mr. Denton and are now the property of Vanderbilt University, at Nashville.

The first known Pelvis of *Megalonyx*.

Especial interest is attached to these bones, as the lot includes, fairly well preserved, the major part of the pelvis of the animal—enough of it, indeed, to give a good idea of the character and general form of the part, which, it appears, has heretofore been unknown. Mr. E. W. Claypole, in a full and very satisfactory article on *Megalonyx* and allied forms, published this year in the February and March numbers of the American Geologist, makes the statement that "no pelvis has yet been found, with the exception of a fragment or two." From this I infer that the specimens now presented will be new to paleontologists.

The parts of the pelvis found are:

The two ilia.
Right pubis (a portion).
Right ischium (a portion).
The five sacral vertebræ (some broken).

The ilia are broad and fan-shaped. Their thickened margins, like parts of nearly all the bones of the collection, are to some extent gnawed by some small animal, probably a rodent. The portions of the pubis and ischium, when fitted in place to the right ilium, reconstruct well the right acetabulum, showing both its form and dimensions. The general form of the pelvis of the *Megalonyx*, as indicated by these specimens, recalls strongly that of *Megatherium*. There has been no opportunity, however, for any detailed comparisons.

Other Bones of the Collection.

The bones of *Megalonyx* associated with the pelvis are as follows:

The skull.
Fragment of a rib.
Right humerus.
Right scapula (most of it).
Left tibia.
Seventeen vertebræ (including the sacral).
Fragments not determinable.

These bones are in various degrees of preservation. Some have lost one or more epiphyses. On some, portions of cartilage and tendons still remain. The animal to which they belonged was doubtless young.

It is not my purpose to describe the individual bones. I only add a note as to the skull: Its length, from the occipital condyles to the anterior margin of the first molar alveoli, is 13 inches and 3 lines, a length the same as that of the specimen from Natchez, Mississippi, referred to by Dr. Leidy in his memoir on the extinct sloths in the Smithsonian Contributions, published in 1853. The teeth are entirely

gone, with the exception of some fragments left in the sockets. The cheek bones are mostly gnawed away. In other respects the skull is in a satisfactory condition for study.

Bones of *Megalonyx* previously obtained from Big Bone Cave.

Mr. Denton, in the letter from which I have taken extracts, refers to the finding of large bones 50 or 60 years ago in Big Bone cave, and further says that they are now in Philadelphia. These doubtless are the bones which form one of the collections used first by Harlan and then by Leidy in their descriptions.

I give below a paragraph from Dr. Leidy's memoir, and for two reasons: First, because his description of the state of preservation and condition of the bones of the collection he had would answer as well for those of the lot discovered recently, and now presented to a scientific body for the first time; secondly, because the bones he enumerates so nearly supplement the list I have given. With these facts before me, and both lots coming from the same cave, I thought at one time that the bones of both must belong to the same animal, and I am not certain yet but that it will so prove upon bringing both collections together. Dr. Leidy, in enumerating the specimens of *Megalonyx* available for study, says:

"A collection of bones of a young animal, nearly all of them having the epiphyses detached: They are the left scapula, imperfect; the left os humeri without epiphyses, the right radius without its distal epiphysis, the proximal two-thirds of the right ulna, the right os calcis, the distal epiphysis of the right os femoris, the left tibia without its distal epiphysis, the distal epiphysis of the right tibia, one lumbar vertebra, four dorsal vertebræ with one exception without epiphyses, fragments of three right ribs, fragment of a left rib, and two ungual phalanges of the right hind foot. These were found in Big Bone cave, Tennessee. They are of a yellow color, comparatively light, unchanged in texture, and quite recent in appearance. Several of them are remarkable for retaining portions of the articular cartilage, periosteum, and tendinous attachment; and one ungual phalanx has the nail preserved upon it almost entire. They also present the marks of having been gnawed by some rodent."

Location and History of Big Bone Cave.

Big Bone cave is in the base of a westward-jutting spur of the Cumberland mountains, in the northwestern corner of Van Buren county. It is a little east of a straight line joining McMinnville and Sparta, and not far from midway between the two places. The spur above divides the valley of Cany Fork river from that of Rocky river. The cave, like many others in Tennessee and Kentucky, is in the lower Carboniferous limestone. It has long chambers in which there was once much saltpeter earth. In 1811–'12 the most accessible part of this earth, running in half a mile or more from the mouth, was dug and leached in the process of making nitre. This was at the time a great industry, and quite a village was temporarily built up around the mouth of the cave. It was during the period of this work that the large bones were found and suggested the name by which the cave has ever since been known.

Remarks were made by Professor E. D. Cope.

The next paper read was entitled—

NOTES ON THE CRYSTALLINE ROCKS OF CENTRAL TEXAS, WITH MAPS.

BY THEODORE B. COMSTOCK.

Remarks were made by Professor C. R. Van Hise, to which the author replied.

The following paper was then read:

THE CIENEGAS OF SOUTHERN CALIFORNIA.

BY EUGENE W. HILGARD.

A *cienega*, in the parlance of the native Californian, is a limited area showing a growth of water-loving plants, appearing sporadically in otherwise arid surroundings—usually hillsides or valley margins—and occasionally giving rise to flowing springs. The economic importance lately attained by these cienegas as sources of irrigation water by the aid of artesian borings, and some peculiarities of structure upon which their occurrence in that particular region seems to depend, justify at least a brief presentation of the facts to this body.

A simple and typical case in point is presented, for instance, by San Antonio creek, a stream issuing from a cañon in the Sierra Madre near the town of Pomona, in the San Bernardino valley, Los Angeles county. It is near the present divide between the adjacent drainage basins of the San Gabriel river on the west and the Santa Ana river on the east. Though a small stream, carrying only from 700 to 800 miner's inches of water in summer time, it has formed in front of its exit from the cañon a débris cone or "fan" having a radius of seven or eight miles, of which the apex, near the cañon mouth, is between 400 and 500 feet above its base. On the slopes of this fan, as well as near its base, there appear numerous cienegas, some less than an acre in area, while others range up to twenty acres and over. In some of these, large sycamore trees are the only unusual indication amid the "bee-pastures" of white sage, cactus and other plants characteristic of the dry mesas of the south. In others there is added the willow and clumps of "tule" (cat-tail) and other swamp plants. From some, springs issue naturally; in all, shallow dug wells find water; in many of them, artesian bores have been made with good success. The deposits penetrated in these bores are, of course, such as may be expected in a débris-fan; but they vary so quickly and completely in wells only a short distance apart as to show that the ancient portions of the fan have been formed under a régime exactly like the present—namely, an alternation of very coarse deposits of gravel and large cobbles such as are now carried by the stream during the torrential floods to which the high ranges are subject, with fine silt and even clay, which are practically impervious to water. The abrupt diminution of velocity on emergence from the cañon results in the quick accumulation of cobble ridges or "kames," which sometimes change the main channel, within a few hours, to a totally different direction. It is obvious that in past times such changes of channel have thrown the water of the creek from one drainage basin to the other; at present it discharges toward the Santa Ana basin, but unless artificially prevented there is no reason why it may not some time revert to the San Gabriel watershed.

If we imagine the structure that must result from such a mode of accumulation of a débris-fan, the sporadic appearance and peculiar localization of the cienegas (being the points at which the water fed into the cone at the mouth of the cañon is forced near to the suface either by a cross ridge or by the termination of a water-bearing cobble-bed underlain by an impervious layer) is easy to understand. But it is also obvious that the continued supply of water from the stream into the various old channels of the débris cone must depend upon the maintenance of the open gravel surface at the apex of the cone. When this is wholly or partially closed, whether by natural or artificial processes, then, the source of supply being stopped, the springs or artesian wells dependent upon it must diminish or cease to flow. Such variations and stoppages have already been experienced at several points, and as they may prove very costly, if not disastrous, to heavy investments already made, it is quite important that the need of keeping the area of infiltration open for the winter floods should be fully understood by the populations concerned. When this is attended to it is obvious that we have here natural storage reservoirs for flood waters, annually replenished and likely to be fully refilled each season, no matter how heavy may have been the drafts made upon them during the preceding irrigation season.

The most extensive example of débris-fan storage of flood waters thus far known to me occurs in the upper San Bernardino valley, at the head of which two large streams—the Santa Ana river and Mill creek—emerge from narrow cañons, at whose outlets there are truly phenomenal accumulations of huge bowlders, which in time of flood are tossed about by the torrents with a thundering noise sometimes audible miles away. Here are many square miles of open cobble surface, into which flood waters can be and are absorbed with the greatest ease, although in the usual channels of the summer flow the bottom is made sensibly waterproof by finer sediments. Costly tunnels have been driven through these cobble-beds under the impression that large amounts of water could be thus collected; but while the constant drip proves the perviousness and absorbent nature of the deposit, that very circumstance prevents the gathering together of any very large supply of water in the relatively insignificant areas of the artificial drifts.

From the head of the débris-fan of Mill creek to its base, near the town of San Bernardino, the distance is between 12 and 14 miles, according to the initial point chosen; the fall of the surface within the same distance is between 600 and 700 feet. The average width of the valley is about 10 miles, and artesian borings have shown the gravels and cobble to be nearly a thousand feet in thickness within a mile of the southeastern edge. This enormous gravel mass, filled with water from the floods of the two streams, forms a natural reservoir of such magnitude that the drafts thus far made upon it by the numerous boreholes sunk in the lower valley have failed to show any such degree of mutual interdependence as is usually observed in wells situated short distances apart—a fact which I have ascertained by experimental measurements made under proper conditions. This relative independence of the flow of contiguous wells also indicates that the water-bearing stratum consists of gravel so large and so open that the water mass may be considered as exerting its pressure rather freely in all directions; yet on reopening a closed well there always exists a material accumulation of pressure, which takes several hours to recede to its normal amount.

Besides the artificial outlets mentioned, however, there is a number of natural outlets on the slope of this great gravel reservoir. The most conspicuous is the

source of Warm creek, the stream which has been appropriated for the purpose of irrigating the well-known colony of Riverside. Warm creek has no visible connection with any of the streams that descend from the Sierra Madre; it rises in the valley itself, fully three miles away from the foot of the range. There is no obvious reason for its being there, but the water gathers from little rills and ditches within a space of about a quarter of a mile, acquiring within that distance nearly its full volume of from 2,000 to 2,500 inches during the dry season. At other points, also, "artesian" springs rise with considerable force and volume, and in the immediate floodplain of the Santa Ana river, rivulets gather at many points on the margins, at the foot of the bluff, some 7 or 8 feet above the river channel, and flow toward the latter to increase the volume of the stream. It thus happens that "the entire flow of the Santa Ana river" has been appropriated at at least three different points, each appropriator receiving a good flow, and that in the absence of any obvious important additions from incoming streams. As may be supposed, bore-holes sunk in this region of spontaneous flows encounter at very small depths (from 120 to 150 feet) very copious flows of artesian water, in cobble-beds; while near the border of the valley not only is a greater depth required and the outflow less, but the materials penetrated are much finer.

Since the terraces of reddish loam that border the foot of the Sierra Madre from the head of the valley to the San Gabriel river indicate plainly that the subdivision of the valley into two drainage basins is a comparatively recent event, it does not seem improbable that the artesian reserve referred to might be tapped by deep borings much farther westward than has heretofore been attempted; perhaps within easy reach of the city of Los Angeles.

A very striking exemplification of the origin of cienegas exists in the valley of Temescal creek, one of the southern affluents of the Santa Ana river, in San Bernardino county. This creek is really the natural continuation of the San Jacinto river of San Diego county; but an intervening lake basin (Lake Elsinore) prevents actual flow from the latter stream to the Temescal valley, save in seasons of extraordinary rainfall. Its water is supplied almost entirely from the cañons of the Santa Ana mountains, which have a rather copious rainfall in their higher portions. At the head of the valley there is a small lake (Lee lake), which, with no visible inflow, nevertheless has at its lower end a steady outflow of about 400 miner's inches of water during the dry season, thus forming part of the water supply of the "South Riverside" colony. Examination shows that the lake is fed entirely by a series of springs, or rather an almost continuous ooze, from the enormous masses of granitic and other débris that have accumulated in front of the two uppermost cañons of the Temescal valley, and which reach entirely across the valley to the foot of the (Temescal) range opposite. These débris masses are so porous that actual surface flow very rarely occurs, and no well defined bed for a stream exists save where, close to the lake basin, the materials are relatively fine. Evidently the main body of the rainfall gathered into these cañons is stored in the coarser portions of the débris-fans above.

Below this lake basin the Temescal valley is divided lengthwise by a series of low ridges formed of materials mostly impervious to water, of Tertiary age. In front of the cañons of this lower portion of the valley similar great débris masses have accumulated also; but since the impervious ridges mentioned prevent the outflow of water save during actual freshets (when small streams pass through gaps in the ridges), extensive cienegas have been formed between the valley ridges and the foot

of the Santa Ana range. In these, as in the upper San Bernardino valley, "artesian" springs rise at many points, and vegetation remains bright green all summer. Borings thus far made have developed a very copious artesian flow, and a tunnel driven through one of the clay ridges toward the cienega was suddenly inundated when its face reached the gravel of the débris mass, about 40 feet below the surface. The artesian wells and natural surface flow from these cienegas, so far as developed, yield an aggregate flow of nearly 600 miner's inches, which can doubtless be materially increased; and this, with the flow from the lake above, constitutes the water supply for the colonies below.

These examples, which could be greatly multiplied, show sufficiently both the nature and origin of the cienegas, and also their practical importance as sources of water supply, which calls for a more careful survey of their extent of occurrence than has heretofore been made. While they do not render the establishment of artificial storage reservoirs superfluous, they do supplement them locally to a very material extent, rendering it possible to occupy for agriculture large areas that otherwise would have remained arid for many years to come. But there arises the question as to the geographic limits within which these natural storage reservoirs may reasonably be sought, for it is notorious that they are not usually found, and the name and idea of the cienega is not generally known, in the northern portions of California.

The essential condition of cienega formation is manifestly the opportunity for the abundant formation of deposits of exceptionally coarse and pervious gravel and cobbles near the points where the cañons emerge from the mountains. This, again, is necessarily conditioned upon the occasional occurrence of violent, torrential rainfall in the mountains, alternating with periods when quiet deposition allows of the formation of water-shedding layers. Another condition appears to be the ready weathering of the parent rocks into rounded forms, by which close packing is prevented, so that abundant interspaces are permanently maintained.

Both conditions are fulfilled to an unusual extent in the granitic ranges of southern California. The rock is rather easily disintegrated, first into larger and then into smaller rounded masses, from which large quantities of very coarse angular sand have been detached, and which continue to disintegrate rapidly when exposed to the air, but are relatively stable when submerged in the débris mass, and so maintain porosity. Such granitic or granitoid material forms the main body of all the larger cienegas I have examined in southern California; and the remarkably large proportion of potash contained in their waters in consequence is of no small economic importance.

It is therefore reasonable to presume, and it seems *à priori* probable, that a concurrence of the two conditions, climatic and petrographic, is requisite for the formation of cienegas upon a practically useful scale; and the extent to which this concurrence actually exists, geographically, is a question of no little practical interest.

Professor Hilgard's paper was discussed by Professor C. R. Van Hise.

The next paper was on—

THE CHATTAHOOCHEE EMBAYMENT.

BY LAWRENCE C. JOHNSON.

Looking upon a map of the Gulf of Mexico one prominent feature, certain to attract attention, is a deep bight running up into middle Florida, called Apalachee bay. During Miocene time the coast line was very different. The continent on the Alabama side extended down Chattahoochee and Chipola rivers to the vicinity of Chipola, or so as to include part of Jackson county in Florida. The Mariana building stone, which is an orbitoidal limestone of the Vicksburg type, formed the shore during this period. To the eastward at the same period the continent did not reach into the peninsula. The shallow Miocene sea, however, toward the south was close set with Eocene islands in the Suwanee region, their sites now marked by the distinctive deposits of the phosphate belt.

Erosion in the valley of Suwanee river and in its western branches exposes the Eocene orbitoidal limestone in many places, and, strange to say, of a type slightly differing from that of the west, but resembling that of Cooper river, South Carolina. Between these two limestone headlands of the Miocene period lie the greater portion of the counties constituting what is known as middle Florida.

To avoid conflict with a mountain nomenclature, this ancient extension of the bay of Apalachee may be called *the Chattahoochee embayment*. The Chattahoochee river doubtless poured into the head of it on the northwest, and constituted then, as it still constitutes, the principal contributor of material for its sediments.

The general appearance and character of the rocks and fossils of this embayment stamp them with a unity of type. The rocks are all limestones, but generally so impure as to be often almost sandstone. The older of these beds are more compact and harder than the Vicksburg rocks, and even where not silicified and where not a mere calcareous sandstone the fossils do not retain the original shells imbedded in a softer matrix, but have their lime leached out and their cavities often filled with calcite. These rocks, then, are more insoluble, more unyielding, than other known orbitoidal limestones. Upon this fact depend many of the phenomena of this part of Florida.

Though spoken of as displaying a unity of type, it not intended to treat the rocks and fossils of the Chattahoochee embayment as identical throughout; there are variations, which may be exhibited by sections.

Considering the embayment as having become dry land by the usual process of continental uplift, there is to be anticipated a general dip toward the south, and observations show as much. Recent studies in Florida have brought out another fact, viz, that there is a westerly dip toward the axis of the embayment. This is very obscure in the eastern part, but very manifest in that nearer the Chattahoochee river. As a consequence, there is a thinning out of the strata eastward and northward, and a deepening of accumulation toward the west and south. The southward dip is well shown on the river. Descending the river, the last seen of the Vicksburg rocks is about Port Jackson, a short distance above the mouth of

Flint river; the next rocks seen are at the old Chattahoochee landing, on the road to the village, and it is upon these that Mr. Langdon founded the Chattahoochee formation. The northern and eastern extension, in exactly this form, has not yet been determined. Southward it has a very considerable inclination, so that instead of covering high hills, as about Chattahoochee, it sinks to the place of the lower rocks at Aspalaga landing and goes out of sight at Rock bluff.

Fossils are not common in this basal portion, and their place is usually filled with calcite; and the rock is of considerable weight and density. At Aspalaga, however, a layer near the top is filled with casts and impressions of gasteropods and corals, including conspicuously the large *Orbitulites floridana*.

This phase of the formation constitutes the upper or country rock of Gadsden county. It is largely exposed on Little river and its branches. It is of interest as the bed rock upon which lie the phosphates of this county, notably at Aspalaga, where the top of this layer is 40 feet above the water; above lie as much more of brown and dark-colored clays or altered marls, with thin layers of shells; all very much decomposed except an *Ostrea* and a large pecten (*Pecten madisonius*) resembling that of Waldo, on the eastern side of the peninsula. For the sake of distinction, we may call this upper bed the Aspalaga* phase of the Waldo formation.

The following section displays the relation of the beds at Aspalaga (on Apalachicola river, in section 35, township 3 north, range 7 west):

	Feet.
1. Pine level with much gravel in poor sand	†10
2. Sands of number 1 washed off in places expose a very hard red clay alternating in places with ferruginous sandstone, forming cliffs; some also pure enough for limonite	20
3. Stratified sands and sandy clays, water bearing, having springs at the base and in intercalated clay beds ‡	50
4. Tough calcareous clays, including the residuum after lime of the shells is leached away, generally dark colored §	60
5. Limestone forming bluffs for over two miles, unevenly scored by erosion; rising higher toward north, subsiding toward south; passes beneath the river at Rock bluff, though very high at Chattahoochee ‖	40

At Rock bluff, five miles south of Aspalaga, the heavy rocks of the Chattahoochee lie below the water line. The clays of number 4 of the preceding section are here much reduced, while the stratum itself increases in thickness and carries more of the calcareous sand, with numerous well preserved pectens and other shells.

* The old site of Aspalaga village and post office is in section 35, township 3 north, range 7 west. Rock bluff is on Chattahoochee river, 5 miles south of Aspalaga, Chattahoochee being about the same distance northward.

† Elevations and thicknesses ascertained by aneroid.

‡ 2 and 3 may be assigned to the Lafayette formation.

§ Exposure not clear enough to see subdivisions, but in gullies some decayed shells are found, as well as *Pecten* and *Ostrea* which resemble forms found at Waldo; at one spot in a trough of number 5 a phosphate bed occurs. This member may be called the Aspalaga clays.

‖ In the lower layers the fossils are obscured by infiltration of calcite; the upper layers are full of fossils, corals, and lamellibranch, and *Orbitulites floridana*. At Mount Pleasant this upper layer is found over 100 feet above the river.

A section in the vicinity (on Sweetwater creek) where phosphate beds occur in or above this calcareous soft sandy rock well displays the relation of the members in this part of the Chattahoochee embayment:

	Feet.
1. Columbia sands of river origin; variable in thickness on account of erosion; wells at top of ridge give	20
2. Alum bluff or Chipola marl; at this point less than	*15
3. Aspalaga marl; † pectens and oysters in gray calcareous compact sand, with darker clay at base	20–40
4. Aspalaga phase of Chattahoochee formation, or the upper layer extending eastward over high lands of Gadsden county; fossiliferous; estimated to be	30
5. Lower portion of Chattahoochee formation, generally without fossils; more calcareous than number 4; calcite in cavities	‡40
6. Place of supposed underlying Vicksburg rocks not seen on the river, south of Port Jackson, above the mouth of Flint river	

In this section a thin layer of another variety of sands and clays appears, covering the gray sandy limestone of the pecten-bearing beds and covering the peculiar phosphates of this region. It is doubtless an overlap from Alum bluff of the Chipola deposit. It may be traced westward and northwestward into Alabama, on the waters of Yellow river; but eastward it stretches little beyond Ocklocknee river, after crossing which it becomes lost beneath the later formations on Lost creek and Sopehoppy river. The overlying beds (number 3 of the section) extend up Ocklocknee and Little rivers some distance, and still further eastward into southwestern Leon county and the northwestern part of Wakulla county. Between Alum bluff and the Gulf the formations and their relative proportions have not yet been determined.

Thus, a great part of Jackson county, as well as all of Calhoun, Gadsden, Liberty, and Franklin, with half of Wakulla and the southwestern part of Leon counties, Florida, constitute the Chattahoochee embayment in its most restricted sense.

In addition to the geologic structure, there are superficial characteristics by which the embayment may generally be recognized: Gadsden county has very much the appearance of the high, rolling pine lands, its natural forest covering being a mixture of oak and hickory, which prevails in the adjoining states of Alabama and Georgia. It abounds in springs and running streams; there are no lakes, and none of the sinks so common in other parts of Florida. In all this more restricted embayment the lakes, springs, and sinks prevailing in the eastern portions of middle Florida form no part of the topography: because, first, the most soluble and cavernous rock of the region (the Vicksburg limestone) lies deep beneath the surface, probably little, if any, above tide; second, the impure limestones are little soluble; and, third, the later beds are of great thickness.

* This deposit runs southeastward to Ocklocknee and southward to the mouth of the river, and westward and northwestward to Alabama, with a thickness of 4 feet.

† The phosphates are in or over this deposit.

‡ It is estimated, from observations at Aspalaga and Chattahoochee and other places north of Rock bluff that the thickness of these two exceeds 100 feet.

Defined in a more extended sense, the Chattahoochee embayment will stretch out almost to the basin of Suwanee river, or at least to about the middle of Madison county. The rocks found in this extension present quite another aspect. When collections were first made in this part of Florida a few years ago, the leading type was called the Wakulla formation because it abounds in the vicinity of the springs of that name. The material was taken out of a deep well two miles southwest of Tallahassee. The leading features of this rock were an abundant *Hemicardium* (species not determined so far as the writer is aware) and the large *Orbitulites floridana*, together with many land shells. The rocks vary greatly in material; sometimes a quite pure limestone, at other places, or in other layers, aluminous and silicious. The collection from the well shows a good limestone, with calcite filling the cavities left by removal of the substance of the shells, and with some lumps or streaks of chert; the deposit was said to be 80 feet thick. Two miles northwestward and one mile northward there are hills fifty to one hundred feet higher, covered with Lafayette sand.

The excavation at the Saxton mine, $3\frac{1}{2}$ miles west of the court-house in Tallahassee, reaches this rock, and is interesting because showing that here again its surface is the place of phosphates. The section here is as follows:

	Feet.
1. Soil and subsoil (Lafayette sand)	6–10
2. Greenish plastic clay; stands high heat; has a few nodules of hard phosphate; of doubtful genesis	17
3. A compact, friable sand, very white and pure; of doubtful genesis	6– 9
4. Dirty clay, with nodules of phosphate and rotten leaves; also of doubtful genesis	3
5. Sandy clay, colored by organic matter, leaving fragments of fossils all leached away except a chalcedonized *Ostrea*	$1\frac{1}{2}$
6. Whitish sandy clay, phosphatic, with lumps of pure white clay	8
7. Yellowish white clay, phosphatic, sandy, with peculiar irregular masses of very hard phosphate*	12
8. Bed rock, dug into only 2 feet; soft, pure limestone without fossils, corresponding with first rock struck in well 2 miles southwest and 50–100 feet lower; fossils identified with those of the Wakulla beds; similar to those of Weelaunee and Lloyds	

In this part of Florida the great springs or "rises" begin near the coast, and farther back in the higher ground numerous sinks and lakes occur. This is undoubtedly because the strong, insoluble sandy or aluminous limestones thin out, as do the overlying impervious clays, so that there is nothing to prevent infiltration of surface waters, and thus the formation of sinks and subterranean rivers in the porous limestones of the older formations. When the sinks or outlets are stopped, or partially so, lakes and ponds, or at least funnel-shaped depressions take their places. An actual section taken where the later rock and the superficial covering are sufficiently thick to prevent sinks will illustrate the relation. A deep excavation at Weelaunee, Jefferson county, Florida (sections 35 and 36, township 1 south, range 4 east), gives the following succession:

*The matrix of number 7 is said to run $15\frac{3}{4}$ per cent and the rough, hard nodules 80 per cent of phosphate of lime.

		Feet.
1.	Well-defined Lafayette sand, as seen on St. Augustine road and northward to Monticello; water-bearing	40–60
2.	Solid, impervious sandy clays, very dark red; seen in washes; pierced in deep well at Weelaunee; no fossils, no stratification lines, but traces of both; not water-bearing*	30–50
3.	Limestone, sometimes pure, sometimes very impure; full of fossils, among them *Orbitulites floridana*, a *Hemicardium* very numerous (species unknown), and many shells of *Helix*, *Pupa*, and other land snails; burnt for quicklime at Weelaunee; considered equivalent to Wakulla rock of Tallahassee and Lloyds, and there approaches 100 feet; here penetrated in Weelaunee excavation (without getting through)	50

Between the locality of the above section and Tallahassee the St. Augustine road crosses that part of the depresssed surface, south of Chaires station on the Florida Central and Pensacola railway, known as the "natural bridge of St. Mark river." All around the surface sounds cavernous to the tread, and there are numerous sinks in the vicinity.

From this part of the St. Mark country, at an ever-increasing distance from the high hills of Lafayette sand, diverges a low terrace of Columbia sands overlying silicious limestones and sandstones of no great thickness; and this arenaceous rock crosses all the small streams which empty into Apalachee bay, beginning at Aucilla, by natural bridges; and this ancient beach line marks the boundary in that direction of the Chattahoochee embayment in its most extended definition. On Fenahollowa river only the bridge has been washed away, but enough remains to identify the old natural structure and its locality.

A section at the natural bridge on Steinhatcheee river (10 to 12 miles from its mouth), the easternmost of the series, will illustrate the system; and will at the same time well illustrate the relations of the older and the newer Tertiary rocks of Florida:

		Feet.
1.	Sands resembling the Columbia	6
2.	Impure silicious limestone, with a few fossils (as seen eastward at Howard's sink and the big slough one mile east of river); the dip is westerly, and its thickness increases from 2–4 feet to	8
3.	A sandstone (no fossils), thin and broken at Howard's $1\frac{1}{2}$ miles eastward; getting thicker westward toward bridge; probably	3
4.	Hard sandy marl, full of fossils; among them a *Spatangus* and two echinoids, at Howard's sink†	2
5.	Not seen at the natural bridge but well seen at Howard's sink, $1\frac{1}{2}$ miles east, in the river, 1–2 miles north, and at 8-Mile creek, 4 miles northeast of bridge; a soft limestone easily eroded, filled with a *Pecten* (thought to be *P. perplanus*) and innumerable reservoirs of *Nummulites* (*N. wilcoxi* ?)	20

*In genesis this is believed to be a leached, oxidized and altered marl, a kind of formation common in Florida, and proposed to be called *amureaceous*, from *amurca*, the residuum of fruit or olive press—that is, where the insoluble material of a bed retains the place of original deposit, but is altered by meteoric waters.

†These four members constitute the arch of the bridge. Two miles north of the bridge the place of number 4 is filled by an *Ostrea* bed lying upon number 5, the shells resembling *O. virginiana*. Paleontologists are not convinced that the fossils of numbers 2, 3 and 4 of this section are Miocene: they may represent an upper layer of the Eocene (Vicksburg) limestone.

The following papers were read by title:

ON THE SEPARATION AND STUDY OF THE HEAVY ACCESSORIES OF ROCKS.

BY ORVILLE A. DERBY.

This paper is published in full in the Proceedings of the Rochester Academy of Science, volume 1, 1891, pp. 198–206.

PECULIAR GEOLOGIC PROCESSES ON THE CHANNEL ISLANDS OF CALIFORNIA.

BY LORENZO G. YATES.

(*Abstract.*)

The eastward trend of the California coast south of Point Conception causes the summer trade-winds to assume the same direction parallel to the coast. Since the islands of the Santa Barbara channel have been largely denuded of their herbaceous vegetation by sheep and cattle, the shore sands drift heavily to leeward, even as far as from San Miguel, the outermost island, across a four-mile channel to Santa Rosa. This sand fills the cavities left by decaying vegetation, and casts of trunks of trees and shrubs are thus formed, which in the course of time consolidate, and may hereafter puzzle the geologist.

THE PRINCIPAL MISSISSIPPI SECTION.

BY C. R. KEYES.

PROCEEDINGS OF THE SECOND SECTION.

The papers on glacial geology and the Pleistocene formations were read in the Second Section, which met in room 14 of Columbian University, Vice-President T. C. Chamberlin presiding, and Professor Samuel Calvin acting as Secretary.

Vice-President Chamberlin called Professor N. H. Winchell to the chair and read a paper entitled:

THE PRESENT STANDING OF THE SEVERAL HYPOTHESES OF THE CAUSE OF THE GLACIAL PERIOD.

BY T. C. CHAMBERLIN.

This paper was discussed at length by C. H. Hitchcock, N. S. Shaler, Warren Upham, E. W. Claypole, R. D. Salisbury, J. A. Holmes, and the author.

Vice-President Chamberlin resumed the chair, and the following paper was read:

ON THE NORTHWARD AND EASTWARD EXTENSION OF PRE-PLEISTOCENE GRAVELS IN THE BASIN OF THE MISSISSIPPI.

BY R. D. SALISBURY.

A second paper was read by the same author:

ON CERTAIN EXTRA-MORAINIC DRIFT PHENOMENA OF NEW JERSEY.

BY R. D. SALISBURY.

The two papers by Professor Salisbury (printed on other pages) were discussed by C. R. Van Hise, Frank Leverett, E. W. Hilgard, N. H. Winchell, F. J. H. Merrill, T. C. Chamberlin, and the author.

The next paper was on—

INEQUALITY OF DISTRIBUTION OF THE ENGLACIAL DRIFT.

BY WARREN UPHAM.

Contents.

Discrimination of Subglacial and Englacial Drift.

The various drift deposits which are left to us as the record of the Glacial period give far more information of the wane and departure of the last ice-sheet than of its accumulation and stages of advance to its maximum area and depth. Thus we fail to discover the beginning and successive limits of increase of the ice-sheet

until we find its extreme boundaries marked by the outermost of its numerous approximately parallel terminal moraines; but the inner moraines, of which no less than ten have been mapped by the writer in Minnesota and North Dakota, and a larger number by Mr. Frank Leverett in Illinois, Indiana, Ohio and Michigan, tell of stages of temporary halt or re-advance interrupting the general recession of the ice. During the greater part of the second or last Glacial epoch, through the time of general growth of the ice-sheet, while it was performing most of its work of erosion and transportation of the drift, with the incorporation of a large volume of detritus in the lower portion of the slowly moving ice, the only deposits which it made were the subglacial till, or ground moraine, and scanty stratified drift in subglacial water-courses. Outside the glacial boundary during the same time beds of gravel, sand, clay and silt were laid down in the avenues of drainage from the ice-sheet by the streams of its scanty melting beneath throughout the whole year, produced by the heat of friction and the slight access of heat from the earth's interior, and of its plentiful melting above, near its edge, by the sun's heat and by frequent rains each summer. But during the time of departure of this ice-sheet, which is known as the Champlain epoch, very abundant deposition of the drift that had been inclosed within the ice took place, partly as till or unmodified glacial drift, and partly as stratified or modified drift, transported, assorted and laid down by currents of water. Professor James D. Dana * first directed the attention of glacialists to this rapid formation of diverse drift accumulations of Champlain age, and gave this name to the epoch from its fossiliferous marine beds adjoining Lake Champlain, which had been described by Professor C. H. Hitchcock;† and President T. C. Chamberlin ‡ has named the ice-held detritus "englacial drift," this term being applicable to it while it was inclosed and being borne forward within the ice, from which during the final melting it was deposited in many forms, as the upper till, perched blocks, kames, osars or eskers, valley drift, and loess. Besides these deposits derived from the englacial drift when the retreat of the ice set it free, the terminal moraines were formed chiefly or wholly from it during stages of glacial growth and advance; and the drumlins and other masses of subglacial till were also made mainly by gradual additions of material that had been englacial.

Nearly everywhere throughout the drift-covered areas glacial erosion has removed all the preglacial residuary clay which more or less mantled the entire country. This product of the preglacial denudation, and the gravel and finer alluvial detritus of valleys, were plowed up by the ice-sheet and carried forward in the direction of its motion; and portions gathered throughout great distances along the path of the glacial current were mingled and thoroughly kneaded together. Occasional bowlders and rock masses were also supplied on the higher lands by the irregular action of subaërial erosion and weathering before the ice age, ready to be borne along and deposited in the glacial drift. But the ice-sheet commonly did more than to remove the loose material before existing, as is shown by rock surfaces embossed, planed and striated by glacial erosion. In general, far the greater part of the drift was thus worn off, and most of its bowlders were torn and plucked away, from the rock floor over which the ice-sheet moved, grinding

* Am. Jour. Sci., 3d series, vol. v, 1873, pp. 198–212, and numerous papers in vols. x, xii, xxiii, xxiv, xxvi, and xxvii, 1875–1884. Manual of Geology, first ed., 1862, p. 517; third ed., 1880, p. 543.

† Geology of Vermont, vol. i, 1861, pp. 156–167.

‡ U. S. Geol. Survey, Third Annual Report, for 1881–'82, p. 297.

it with the drift material contained in its basal portion under the weight of thousands of feet of ice. The large proportion of limestone present in the sand and finely powdered rock of the drift in regions of limestone formations demonstrates, as Chamberlin has shown, that the drift was chiefly derived from glacial wearing of the bed-rocks.* It should be added, however, that the depth of the glacial erosion was probably nowhere so great as to change the principal and grander topographic features of the preglacial contour. The most important influence of glacial action upon the topography was usually the removal or partial wearing away of comparatively small projecting knobs and the filling up of depressions and valleys, bringing the surface to a more uniform contour than before the ice age.

If the rocks underlying the drift have been so universally glaciated, losing their preglacial mantle of loose superficial deposits and further suffering almost everywhere much abrasion by the ice-sheet, it is evident that at some time between the beginning and the end of the glacial period every part, even every square rod, with rare exceptions, has been subjected to grinding and rasping by the ice and its enclosed drift. The thickest drift deposits when removed are found to have rested on firm and sound rock, which bears no trace of preglacial weathering, but is planed and striated by ice-wearing. We therefore must conclude that earlier or later all of the drift has been plowed up and borne forward within the ice, or pushed and dragged along beneath it, strongly held in the grasp of the bottom of the ice. Any mode of action which seems consistent with the observed glacial erosion of the rock floor would require intermingled ice and drift to be swept over it during some part of the glacial period. All the drift therefore has been at some time essentially englacial, being transported while embedded in the ice.

But the masses of till forming slopes upon higher hills of rock, sometimes on their lee side, sheltered from the ice-current, but often on the stoss or exposed side, and not rarely in both situations, then almost enveloping the rock hill, were evidently deposited beneath the ice-sheet as subglacial till or ground moraine, and afterward remained undisturbed in their present place while the ice-current continued to flow over them. Indeed, the position and character of these slopes of till prove that they must have been gradually accumulated by the addition of drift which had been englacial and became lodged on their surface. The massive hills of till, round, oval, or elongated, which are called drumlins, have many features analogous with the slopes of till just noticed, and like them are doubtless subglacial accumulations consisting similarly of drift that was formerly englacial, amassed in these hills by gradual accretion. Lower tracts of till, also occupying the greater part of the drift-bearing area, show by their composition, hardness, and obscure lamination that they were subglacial deposits.

Among further proofs of the accumulation of much of the till under the ice, as its ground moraine, are bowlder pavements, where a surface of till has been evidently planed and its bowlders striated by glacial erosion. Again, one portion of a rock surface has been occasionally planed and striated by a glacial current moving in a different direction from that which similarly eroded an adjacent portion of the same ledge; and the two areas often have different slopes, their line of meeting being a beveled edge. One part of the rock has been protected from the later

*U. S. Geol. Survey, Third Annual Report, p. 312; and Sixth Annual Report, memoir by T. C. Chamberlin and R. D. Salisbury, "The Driftless Area of the upper Mississippi," pp. 241, 247, 255; also Am. Jour. Sci., 3d series, vol. xxvii, 1884, p. 388. Compare "Composition of the Till or Bowlder-clay," by W. O. Crosby, Proc. Boston Soc. of Nat. Hist., vol. xxv, 1890, pp. 115-140.

erosion by a thin covering of subglacial drift. In such cases the glacial deflection has probably oftener been due to changes in the boundary and slopes of the ice-sheet, and consequent deviation of its currents during its general recession and departure, rather than to two distinct glacial epochs.* A third proof of subglacial accumulation is the fluxion structure observable at certain planes in many till deposits, indicating that a surface layer of the till was frozen in the bottom of the ice and dragged along over the underlying principal mass, with a shearing movement of particle upon particle.† In this way, apparently, the glacial wearing and striation of the bowlders and pebbles of the till was mostly done.

Without attempting to review the vicissitudes of the glacial period, its two principal glacial epochs with their varying stages of ice advance and temporary retreat, and the long interglacial epoch, we see that during the progress of the period all the surface of the bed rock was glaciated, and all the drift material was for some time englacial or at least was grasped and borne forward by the basal portion of the ice-sheet. In its passage across hills and mountains it is easy to understand that the ice, closing up in the lee of the rock highlands, tore from them many fragments, bowlders of large and small size, and rasped off much fine drift, to be locked in the embrace of the ice as it flowed onward hundreds, or sometimes even thousands, of feet above the surface of the lowlands; and even on many portions of the nearly level expanses of the St. Lawrence and Mississippi basins eddying convergent and divergent glacial currents doubtless conveyed more or less of the drift upward from the land surface into the lower part of the ice. At length, when the second or latest ice-sheet attained its greatest extent and thickness, much englacial drift was contained within its mass, mostly in its lowest 1,000 or 500 feet, and extensive deposits of subglacial till lay beneath it.

Deposition of the Englacial Drift during the Departure of the Ice-sheet.

Turning our attention to the Champlain epoch, or time of departure of the latest ice-sheet, let us inquire, as the themes of this paper, What was the manner of deposition of the englacial drift during the final ice-melting? What inequalities are observable in the distribution of the englacial portion of the till? Why is it abundant on some tracts and scanty on others? How was the englacial drift related to the terminal moraines? Can we discover through determinations of the volume of the englacial drift a probable estimate of the time occupied in the accumulation of the moraines? In what forms was the englacial drift left by the departing ice? How much was laid down directly by the ice, and how were other parts modified and unevenly distributed through the assorting, transporting, and depositing action of water in rivers, lakes, and the sea?

The recession of the ice-sheet, when warm climatic conditions returned, was by rapid melting upon a considerable breadth, probably 100 to 200 miles or more of its border, which was thus gradually pushed back across all the drift-bearing area. During the entire summer and much of the spring and autumn of each year the superficial melting or ablation of the ice produced many rills, brooks, and rivers. Hydrographic basins were thus formed on the ice surface, resembling those of a

* Warren Upham, Geology of Minnesota, vol. i 1884, pp. 505, 519. T. C. Chamberlin, "The Rock Scorings of the Great Ice Invasions," U. S. Geol. Survey, Seventh annual report, for 1885–'86, pp. 200–207.

† Hugh Miller, Report of the Fifty-fourth meeting of the British Assoc. for the Adv. of Science, Montreal, 1884, pp. 720, 721.

belt of country along a sea coast; but the glacial rivers and their large and small branches had much steeper gradients than those of the present river systems on the land surface, and often or generally they flowed in deep ice-walled channels, more like cañons than ordinary river valleys. In the stages of growth and culmination of the ice-sheet it had possessed a nearly level surface of névé or accumulating snow, mainly unflecked by any stone fragment or other drift material, or even dust; but when the final melting had dissolved away its upper portion, the englacial drift began to be exposed upon the surface, and at last on many areas the ice doubtless became buried and concealed by this deposit, as was supposed by Professor N. H. Winchell many years ago,* and as was found by Mr. I. C. Russell last year in his exploration of Malaspina glacier, at the foot of the Mount St. Elias range.† The completion of the ice-melting allowed much of the englacial drift to fall loosely as an unstratified deposit, called the upper till, on whatever surface was beneath the ice, whether ground moraine, or other subglacial drift, or the bed rocks. Previous to this, while the glacial melting was in progress, other large portions of the englacial drift were washed away by the superglacial drainage and deposited in beds of gravel, sand, clay, and silt, partly in the ice-walled channels of the glacial rivers, but mainly beyond the ice-margin. The various formations thus derived from the englacial drift will be more fully noticed in a later part of this essay; and our consideration is here directed especially to the process of dissolution of the ice, releasing the drift which it had held.

Conditions analogous respectively with the growth and maximum extension of the Pleistocene ice-sheets, and with their wane and departure, have been lately made known to us in the case of ice-sheets now existing. The stage of growth or ice accumulation is represented by the inland ice of Greenland, explored by Nordenskiöld, Peary, and Nansen; and the stage of glacial recession, attended by deposition of the englacial drift on the wasting ice surface and afterward on the land beneath, is illustrated by the Malaspina glacier, as before noticed. The explorers of the Greenland ice-sheet describe its surface, excepting near the border, as a vast expanse of névé, with no nunatak or peak rising above it, and with no superficial drift. The fine, gray powder which occurs somewhat plentifully on the western portion of this ice-sheet, called by Nordenskiöld "kryoconite," and believed by him to be cosmic dust, but which Holst ‡ has regarded as a loess-like part of the englacial drift, brought upward through the ice to its surface, appears instead to be dust blown from a mountainous belt of land forming the western coast. On the eastern side of Greenland, where Nansen's ascent upon the ice was made from a part of the shore having little bare land, no noticeable quantity of this dust was found.§ Nansen, in his expedition across the ice between latitude 64° 10′ and latitude 64° 45′, where its width is about 275 miles, encountered no streams of water nor any water-courses at distances exceeding 20 miles inside the ice boundary; and he particularly remarks the absence of moraine débris or erratic blocks even on the outer portions of the ice-sheet, excepting for a distance of "no more than a hundred yards from the extreme edge."‖ But a very remarkable contrast to all this

* Geol. Survey of Minnesota, First annual report, for 1872, p. 62.

† "An Expedition to Mount St. Elias, Alaska," Nat. Geogr. Magazine, vol. iii, 1891, pp. 53–203.

‡ "Dr N. O. Holst's Studies in Glacial Geology," a review by Josua Lindahl, Am. Naturalist, vol. xxii, July, 1888, pp. 594–598.

§ F. Nansen, The First Crossing of Greenland, vol. i, p. 483; vol. ii, p. 479.

‖ *Ibid.*, vol. ii, p. 479.

is afforded by the Malaspina glacier, with its drift-covered tracts occupying a width of about five miles on its seaward border, bearing flowering plants and even forest trees; and by the large rivers of the associated alpine glaciers, one of which emerges from an ice-tunnel, flows for about 1½ miles in a channel open to the sunlight, walled by ice and having ice beneath it, and then enters the mouth of another tunnel and disappears.*

Though the ice-sheet of Greenland has formerly been more extended and deeper than now, as is shown by glaciation of the rock surface high up on the sides of the fjords, it has probably during several centuries been on the increase. There can be little doubt that the climate at present is prevailingly colder than during the prosperous period of the Norse colonies, between 900 and 500 years ago. By its increasing accumulation, therefore, we may account for the contrast between the Greenland ice, which has so little englacial and superglacial drift even near its edge, and the partially drift-buried Malaspina glacier in Alaska; for there, according to Russell, the ice has probably been on the wane during the past 500 or 1,000 years and at present is somewhat rapidly receding. Greenland is a picture of the last glacial epoch at its culmination; Alaska, of the Champlain epoch, of the final melting of the ice-sheet and deposition of its englacial drift. The continuation of these researches, now being prosecuted by Robert E. Peary and by Russell, may be expected, therefore, to bring much further light on the history of North America and Europe in the Pleistocene period.

Tracts of abundant Englacial Drift.

New England.—In Maine the maximum depth of the till is stated by Professor George H. Stone to be about 100 feet. Over the areas of clay slates he doubts that its average depth is greater than ten feet, but in some granitic regions it appears to average 50 or perhaps even 70 feet in thickness. The average over the whole of Maine is estimated by Stone to be probably between 30 and 50 feet.† A considerable fraction of this, not less than a tenth and perhaps as much as a fifth, must have been enclosed in the ice at the time of its final melting; for the abundant osars, kames, valley drift, marine clays, and deltas of sand and gravel, which this author has so well described,‡ were derived by water transportation from the englacial drift, and doubtless much besides remained to be dropped on the surface as the upper part of the till.

In New Hampshire, which includes the most mountainous portion of New England, after several years of work on the state geological survey, I estimated the average thickness of the part of the till finally supplied from englacial drift to be between three and four feet, this being the mean of sixty carefully observed sections; and the modified drift, which was also englacial, has nearly the same volume. The whole of the englacial drift in this state was therefore approximately equal to a sheet seven feet thick.§ To this we must probably add 12 or 15 feet for the mean depth of subglacial deposits of till (which I now think that I then underestimated), giving about 20 feet in total for the average thickness of all the drift. In the White mountains and in very hilly districts the amount of drift is usually less than the average, many areas being mainly bare rock; but in a few

* "An Expedition to Mount St. Elias," pp. 106–112, 185–188.

† Proceedings of the Portland Society of Natural History, Nov. 21, 1881.

‡ Am. Jour. Sci., 3d series, vol. xl, 1890, pp. 122–141.

§ Geology of N. H., vol. iii, 1878, pp. 291, 292.

townships near the coast it is more, attaining there an average of 30 or 40 feet. The distribution of the englacial drift, so far as can be judged by the derivative stratified beds, was somewhat uniform throughout this state, while the subglacial accumulations are very unequal and are wanting on perhaps half of its area.

Dr. Edward Hitchcock estimated the maximum thickness of the drift in Massachusetts, excepting the heavily drift-covered southeastern counties of Plymouth and Barnstable, to be 100 feet, and its average thickness 20 or 25 feet.* Some of the drumlins of Boston harbor and of Scituate give evidence of rapid accumulation, and show that the ice-sheet passing over them was plentifully charged with englacial drift which lodged on their surfaces; but neither there nor elsewhere have I been able to determine that extraordinary amounts of ice-held detritus were deposited as superglacial or upper till. The mean depth of this deposit is probably about the same as in New Hampshire, and its averages in different districts may range from one or two feet to five or perhaps ten feet. Besides, there is much modified drift spread along the river valleys and on lowlands, becoming most conspicuous southeastward, near the terminal moraines, where great thicknesses of gravel and sand, washed from the departing ice-sheet, form extensive tracts, including the fore-arm of Cape Cod.

Vermont, Connecticut, and Rhode Island agree nearly with the foregoing as to the amount and characters of the drift. For the whole of New England its volume is probably equal to a uniform sheet 30 or 40 feet thick, of which about a quarter part was englacial at the time of final melting of the ice.

New York.—No other state surpasses New York in contrasts of topography and in diverse development and distribution of the drift. From Syracuse westward along a distance of 60 miles the traveler on the New York Central railroad sees a profusion of drumlins 50 to 150 feet in height, trending from north to south in parallelism with the glaciation of the region and with the neighboring "finger" lakes, which occupy fjord-like valleys on the south. Through this part of the state, and generally across its southern half, the drift has a greater average thickness than in New England. Northward, between Vermont and Lake Ontario, the Adirondack mountains and some lowland areas have tracts of very scanty drift, while other contiguous tracts are abundantly drift-covered. That a large amount of drift was here enclosed within the ice and set free by its departure is shown by the portions supplied from it to form such extensive gravel and sand plains as stretch from Coeymans northward to Albany and Schenectady, again from near Rome across many miles northwestward, and through Clay and Schroeppel, west of Oneida lake, and from the great bend of Black river northeastward in Wilna.

Minnesota.—A very great depth of drift, averaging 100 to 150 feet, is spread over all the western half or two-thirds of Minnesota; but in the northeastern part of this state a large area was swept bare by the eroding ice-sheet. During the first year of my work on the geological survey of Minnesota, in examination of twenty-two counties lying in its central and western portions, I obtained notes of the order, thickness, and characters of the drift deposits passed through by about 600 wells. Nearly half of these found beneath the englacial upper till a much harder lower till, which was compacted by the pressure of the ice during its subglacial deposition. The extremes in thickness of the englacial till were 3 to 5 feet and 40 feet.† Later

* Geology of Mass., 1841, p. 365.

† Geological Survey of Minnesota, Eighth annual report, for 1879, pp. 109-117.

examinations of other counties in the eastern and the southwestern parts of the state gave three localities where the thickness of the englacial drift deposited at the time of final recession of the latest ice-sheet is very clearly displayed by its stratigraphic relations and by the erosion of water-courses. They can be only briefly noticed here, and the final reports of this survey may be referred to for detailed descriptions of the facts observed, with the full interpretation of their significance. The most eastern of these localities is a plain of englacial till 10 to 20 feet thick, overlying sand and gravel which were deposited from a previously melted ice-sheet, upon a width of five miles and length of probably fifteen miles in Chisago and Pine counties.* Another similar flat tract of till, 16 to 18 feet thick, overlies earlier modified drift near New Ulm.† The third and most interesting group of observations was at lakes Benton, Shaokatan, and Hendricks, adjacent to the outermost or Altamont moraine on the Coteau des Prairies. These lakes lie in water-courses which were channelled in the superglacial drift and continue through the moraine. A thickness of at least 40 feet of englacial and afterward superglacial drift is thus proved to have existed close to the ice boundary, where it was forming massive morainic accumulations.‡

Manitoba.—The great belt of modified drift which extends from St. Paul and Minneapolis north-northwestward by the sources of the Mississippi and Red rivers to the Lake of the Woods and to Bird hill in Manitoba, seven miles northeast of Winnipeg, proves that much drift was contained in the ice-sheet along that distance of 400 miles. Toward this belt glacial currents converged from the northeast and from the west and northwest, bringing doubtless more englacial drift than its average in other parts of the ice-sheet. Its amount at the osar called Bird hill appears to have been about 40 feet.§

Another area to which much englacial drift was brought by convergent ice currents is the region of Riding and Duck mountains and the upper part of the Assiniboine basin, as is shown by the immense supply of modified drift contributed by the retreating ice to the Lake Agassiz delta of the Assiniboine river. Probably more than ten cubic miles of gravel and sand, besides much finer silt and clay, were there washed away from the melting ice surface and swept into this glacial lake.‖

TRACTS OF SCANTY ENGLACIAL DRIFT.

New England.—As an example of tracts known to have very thin englacial drift from their being well nigh destitute of any superficial deposits and consisting in large part or almost wholly of bare rock, we may cite the belt of very rocky, broken country a few miles north of Boston. From Salem, Marblehead and Lynn this tract, occupied by Archean granite, felsites and diorite, extends westward to Stoneham and Winchester, its western part being known as the Middlesex fells. The action of the ice-sheet here seems to have been to sweep away whatever materials it could gather, leaving drift deposits only where they became ensconced in hollows, and are thus shown to have been subglacial.

*Geology of Minn., vol. ii, 1888, pp. 413–417.

†Geology of Minn., vol. i, 1884, pp. 581, 582.

‡*Ibid.*, vol. i, pp. 603, 604.

§"Glacial Lake Agassiz in Manitoba," Geol. Survey of Canada, Annual Report, new series, vol. iv, for 1888–'89, pp. 36–42E.

‖*Ibid.*, pp. 82–90E; Bull. Geol. Soc. Am., vol. 2, 1890, pp. 272–274.

New York.—Remarkable scantiness of drift characterizes parts of Henderson, Hounsfield, Brownville, Lyme, Clayton and other townships of Jefferson county, New York, bordering the eastern end of Lake Ontario, seen by me last autumn during surveys with Mr. G. K. Gilbert on the beaches of the glacial lake Ontario or Iroquois. This tract differs widely in topography and geology from that cited in Massachusetts; for it has a flat, very gently inclined surface, and consists of nearly horizontal beds of the Trenton limestone. The roads often run long distances on the nearly level solid rock; and the soil of the fields, though supplying good pasturage and cultivated crops, is only a few inches or in its deepest parts a few feet thick. This almost continuous but very thin mantle of drift appears to have been chiefly englacial, the bottom of the ice having rested on the rock. Within a distance of a few miles eastward, however, the drift has a considerable depth, and is here and there heaped in beautiful oval drumlins, which rise 50 to 100 feet or more above their base.

Minnesota.—A much larger area having surprisingly scanty drift deposits lies north and east of Vermilion lake, Minnesota, consisting of Archean schists with very hilly contour and plentiful lakes in rock basins. So little drift is found here, and so extensive are the exposures of bare rock, that Professor N. H. Winchell has called it a driftless region;* but it has been everywhere glaciated, and many deposits of subglacial till must be lodged in the depressions between hills and ridges. The whole volume of drift in this region is very little, in comparison with other thickly drift-covered portions of this and adjoining states, and of this little the proportion which was englacial is small indeed.

North of Rainy Lake and the Lake of the Woods.—Continuing northward and northwestward, this area of scanty drift comprises a great extent of country crossed by the Canadian Pacific railway between Port Arthur and the Whitemouth river. Its southwestern limit runs from Vermilion and Net lakes northward across Rainy lake and northwestward across the northern, island-dotted portion of the Lake of the Woods.

Dr. George M. Dawson † and Mr. A. C. Lawson ‡ have referred the gravel and sand beds which are widely spread southwest of this line, about the southern part of the Lake of the Woods and along Rainy river to the mouth of Rainy lake, within the area of the glacial Lake Agassiz, to lacustrine action. This explanation, however, is inconsistent with the restriction of these deposits to a small part of the area of this glacial lake, and with their extension far southward (to the head waters of the Mississippi and to St. Paul, as before noted), beyond the limit of the lake and upon a district that rises in part considerably above it. Instead, the distribution and character of these modified drift beds indicate that they were derived directly from the englacial drift which abounded in the ice-sheet upon this belt. On a large adjoining region next to the northeast, however, the drift is so scanty that much of the surface is bare rock, strikingly contrasting with the country southwestward, which across distances of 100 to 200 miles is wholly drift without a single rock outcrop.

---

*Geology of Minn., vol. i, pp. 117, 131; Minn. Horticultural Society, Annual Report for 1884, p. 398.

† Report on the Geology and Resources of the region in the vicinity of the Forty-ninth Parallel. 1875, pp. 203–218.

‡ Geol. Survey of Canada, Annual Report, new series, vol. i, for 1885, pp. 131 and 139CC; vol. iii, for 1887–'88, pp. 174–176F.

Relationship of the Englacial Drift to the Terminal Moraines.

The irregular distribution of the englacial drift, thus abundant and scanty on adjacent areas, was not apparently dependent on the character of the underlying formations, nor on the altitude or configuration of the land, but rather on the course, intensity, and limits of the great currents of glacial outflow from the central part of the ice-sheet. There is consequently a marked relationship between the inequality of distribution of this ice-enclosed material and the development of the terminal moraines or marginal accumulations pushed out by these glacial currents along the irregularly lobate boundaries of the ice during its maximum stage and at halts in its recession and departure. The axial portion of each ice-lobe was more an area of glacial erosion and less of deposition than its borders; and where the glacial erosion was most severe and prolonged until the departure of the ice the amount of both subglacial and englacial drift is small, the product of erosion being carried to the outer portions of the ice-lobe or district of glacial outflow and there deposited. On this principle we account readily for the deficiency of drift in the extensive region north of the Lake of the Woods, Rainy lake, and Vermilion lake, where the ice pushed strongly southwestward; and for the abundance of drift, much of it modified and therefore known to have been englacial, upon the adjacent belt described between St. Paul and Winnipeg, where the ice currents from the northeast and northwest were pushed together. The same principle also explains the scantiness of drift upon large portions of Labrador and of most arctic lands. Powerful glacial erosion has removed their preglacial superficial detritus and much of the solid rock, sweeping nearly all its drift beyond the coast line.

Even where small tracts of very scanty drift occur, with contiguous tracts deeply drift-covered, as the instances cited in Massachusetts and New York, this explanation probably still holds good, but applies to the latest movements of the ice-sheet on these areas. It has seemed to me probable that the border of the ice during its recession, melted by the returning warmer climate, had generally a more steeply sloping surface than in its time of greatest extent, and that in consequence the rate of motion of the outer part of the ice-sheet was even increased during its final melting. This would account for exceptional erosion and scantiness of drift, either subglacial or englacial, on such limited tracts, and for its being thickly amassed, often in drumlins, not far distant. Whether we consider the inequalities of the drift distribution upon the larger tracts where they were due to the grand movements of outflow of the continental ice-sheet, or upon the smaller tracts where the irregularities of erosion and deposition seem attributable to minor movements during the departure of the ice, it is clearly indicated that the deposition of the drift took place largely beneath the ice and near its boundaries. For example, I find reasons for believing that the drumlins near Boston were chiefly accumulated during the departure of the ice at distances of only a few miles inside its retreating edge.* At the same time, probably, the tract of very scanty drift close to the north was undergoing severe erosion.

Impressive as are the more massive portions of the belts of marginal morainic drift, they must have been far larger if the ice had borne most of its englacial drift quite to its margin, instead of depositing it as subglacial till beneath its comparatively thin border. Professor N. S. Shaler estimates the terminal moraine on the northwest part of Marthas Vineyard to be on the average 150 feet thick, its volume

* Proceedings Boston Society of Natural History, vol. xxiv, 1889, pp. 228-242.

on an area ten miles long and one and a half miles wide being equal to that of Monadnock mountain in New Hampshire.* In the deep north to south valleys of southern New York the morainic deposits, according to Chamberlin, have probably sometimes a depth of 500 or 600 feet.† The Leaf hills, which are the most conspicuous moraine of Minnesota, rise 100 to 350 feet above the surrounding drift-covered country. In Manitoba the moraine that forms the western part of the Tiger hills and the Brandon and Arrow hills is piled up 100 to 250 feet at its highest points; and equally prominent morainic hills, according to Mr. J. B. Tyrrell, lie on the top of Duck mountain, rising to altitudes of 2,500 to 2,700 feet above the sea.‡

All these great moraines, and the less conspicuous portions of the same belts consisting of small hills or having only a moderately rolling contour not more than 20 to 50 feet above the country on either side, were accumulated from englacial drift. Let us consider, therefore, the probable rate of motion of the ice and the amount of its englacial drift, to obtain therefrom some estimate of the length of time occupied in the formation of the moraines. The flow of the glaciers of the Alps, as is well known, varies from one to two or three feet per day; but the daily advance of the central parts of the thick and wide glaciers of Greenland and Alaska, where they enter the sea, is found to be from 30 to 100 feet. Doubtless the continental ice-sheet moved faster than the Swiss glaciers; but the waste from its border by melting must evidently have been far less than the discharge of ice from arctic glaciers that terminate in the sea and are broken into bergs and floated away. If the average amount of englacial drift supplied by the ice-sheet where its moraines are largest be assumed equal to a thickness of twenty feet or even ten or five feet, thus supposing half or a much larger part of the whole volume of ice-held drift to be very near the ground where its onward movement was retarded by friction and it was prevented from contributing very rapidly to the marginal moraine, and if we assume a rate of motion in the higher part of the ice somewhat greater than that of Alpine glaciers, a short computation will show that a few decades of years, or at the longest no more than a century, would suffice for the accumulation of even the largest of our terminal moraines.

Forms in which the Englacial Drift was deposited.

Forms of Drift.—Four classes of drift may be discriminated, differing in their place and manner of deposition, namely: (1) Subglacial till, which was accumulated beneath the ice-sheet; (2) Marginal till, constituting generally the principal mass of the terminal moraines; (3) Englacial till, which, during the departure of the ice, became superglacial and finally was dropped on the land when the glacial melting was completed; and (4) Modified drift, comprising the glacial sediments that were derived directly from the ice-sheet, but were assorted, transported, and deposited by water. The last-named class occurs in many diverse forms. Some of its beds were subglacial and others marginal, as to their place of deposition; but far the greater part of the modified drift was englacial at the time of the final melting, and was then washed away from the ice surface by the streams of its ablation and by rains.

Our enumeration of the various forms in which the englacial drift was deposited during the Champlain epoch, that is, the time when the ice-sheet was melted away,

* U. S. Geol. Survey, Seventh annual report, for 1885–'86, p. 312.

† U. S. Geol. Survey, Third annual report, for 1881–'82, pp. 351–358.

‡ Am. Geologist, vol. viii, p. 22, July, 1891.

may be somewhat brief, the chief point to be brought into view being the inequality of its distribution.

Englacial Till.—The chief characters of the englacial upper portion of the till, as compared with the subglacial lower portion, are its looser texture; its more plentiful and larger bowlders; the prevailingly angular or subangular shapes of its bowlders and smaller rock fragments, whereas they are mostly worn smooth and planed by glaciation in the lower till; and the usually more gravelly and sandy and less clayey composition of the englacial till, owing to the washing away of much of its finer material by the superglacial drainage. To these originally inherent characters we must add the very noticeable postglacial peroxidation and hydration of the small ingredient of iron, giving to the upper part of the till a yellowish-gray color, while the lower part, holding the iron in protoxide combinations and as pyrite, has a darker and bluish color. This change has generally extended through the englacial till, stopping at the more impervious subglacial deposit. Between the two there is also frequently a layer of subglacial stratified gravel and sand from a few inches to several feet thick.

The proportion of the englacial drift dropped as till and that borne away by streams in New Hampshire appear to be approximately equal; and probably it is also true for most other parts of our drift-bearing area that about half of the englacial material became till and half modified drift.

The extremes of thickness of the englacial till in New Hampshire, so far as observed, are one foot and seventeen feet. Its inequality of distribution in other states appears to range, as before described, from almost nothing or only a few feet for its minima to about forty feet for its maxima near massive terminal moraines and where great currents of the ice-sheet converged.

Perched Blocks.—Bowlders and all rock fragments and other drift enclosed in the ice at a considerable height above the ground were borne forward without attrition. This higher part of the englacial drift supplied most of the material forming the terminal moraines, which therefore have a remarkable profusion of bowlders and angular gravel. When the ice-sheet was finally melted its enclosed bowlders were dropped, and they now lie frequently as conspicuous objects on both the lower and higher parts of the land. Perched on the sides and tops of hills and mountains, they at first suggest transportation and stranding by icebergs or floe-ice. Some of these blocks are very large and have traveled far, as the "Three Maidens" at the Red Pipestone quarry in Minnesota, where a single immense bowlder has fallen into three pieces that measure each about 20 feet in length and 12 feet in height, besides several smaller masses.* Two perched blocks, measuring respectively 42 by 40 by 20 feet and 40 by 30 by 22 feet, found by Dr. G. M. Dawson on the eastern foot-slope of the Rocky mountains about 3,300 feet above the sea, and others in the same region up to 5,280 feet, were derived from the Archean area some 700 miles distant.† But the longest distance of transportation of drift within the ice-sheet known on this continent is fully 1,000 miles, from the eastern side of Hudson bay, where it narrows into James bay, to the southwest and south into southern Minnesota.

Kames.—McGee ‡ and Chamberlin § have judiciously proposed the restriction of

*Geology of Minnesota, vol. i, 1884, p. 546.

†Geol. Survey of Canada, Report of Progress for 1882-'83-'84, pp. 147-149C.

‡Report of the International Geological Congress, second session, Boulogne, 1881, p. 621.

§U. S. Geol. Survey, Third annual report, for 1881-'82, p. 299: Am. Jour. Sci., 3d series, vol. xxvii 1884, p. 389.

the term "kames" to the knolls, hillocks, and short ridges of sand and gravel which were heaped at the mouths of glacial brooks and rivers where they left their ice-walled channels and were spread out more widely, thereby losing their velocity and carrying power, on the adjoining land surface. These deposits are frequent on many portions of the general drift sheet, but they are most fully developed in connection with the terminal moraines.

Osars or Eskers.—Prolonged ridges of gravel and sand, or in some tracts of finer silt, narrow and bordered by steep slopes on each side, called osars or eskers, owe their form to deposition in the channels of glacial rivers, walled by ice, but commonly open to the sky.* These peculiar ridges have a great development in Sweden and Ireland, whence their names come, and in Maine, where series extending 100 to 150 miles have been described by Professor George H. Stone.† They are well exhibited also in the valleys of the Merrimack and Connecticut rivers and elsewhere in New England, but are less frequent on the nearly flat expanses of the upper St. Lawrence and Mississippi basins. Associated plains of gravel and sand, terminating in steep escarpments, which descend to adjacent lower land, were deposited in broad embayments of the waning ice-border.

Valley Drift.—In the valleys and on the lowlands uncovered by the departing ice extensive flood-plains of gravel, sand, and clay were spread by the waters of the glacial melting and the accompanying abundant rains. These deposits slope with the present streams, but often somewhat more rapidly; and they continue in large valleys to the sea or to the areas of lakes that were pent up against the receding ice-sheet, and there form deltas and, farther offshore, sediments. Since the departure of the ice, river erosion has carved the valley drift into terraces, and the streams now flow far below their levels of the Champlain epoch.

Loess.—The finest portion of the valley drift, especially where it contains some glacially comminuted rock flour from calcareous formations, is called loess. In the Mississippi and Missouri valleys and on the Rhine this deposit is clearly in large part of glacial origin, being directly supplied from englacial drift; but very similar fluvial beds are now being formed by the Nile, and were formerly spread in great thickness by the rivers of China, where the origin of the silt is referable wholly or chiefly to subaërial denudation

Deltas.—The marine delta deposits of the rivers of Maine, and the marine clays which are spread extensively along the Maine seaboard to a height about 230 feet above the present sea level, were chiefly derived, according to Stone, from englacial drift. Likewise, the great deltas brought by the Assiniboine, Pembina, Sheyenne, and other rivers into the glacial Lake Agassiz are largely modified drift from the ice-sheet and in less amount alluvium from ordinary river erosion. South of Maine much modified drift was borne into the ocean by the Merrimack, Connecticut, Hudson, and other rivers, while their portion of the coast was more elevated than now, so that their marine sediments are still beneath the sea.

All these modified drift deposits are distributed in accordance with the laws of aqueous sedimentation. The kames and eskers, having been laid down in the ice-walled mouths and channels of glacial rivers, now lie as hillocks and ridges, which

* Proceedings Boston Society of Natural History, vol. xxv, 1891, pp. 238–242.

† Proceedings Boston Society of Natural History, vol. xx, 1880, pp. 430–469, with map; Proc. Am. Assoc. for Adv. of Science, vol. xxix, for 1880, pp. 510–519, with map. Am. Jour. Sci., 3d series, vol. xl, 1890, pp. 122–144.

find their only explanation, as to form and origin, in the drainage system of a melting sheet of land-ice. The greater part of the modified drift, however, was laid down outside the receding ice-margin, and occupies the avenues of drainage from the ice to the sea; and where the ice-border lay in or near the sea, or a great lake, deltas of gravel and sand were formed and the finer silt was distributed more widely and thinly by coastal currents.

Influence of adjoining Lakes or the Sea.

From Nantucket and Cape Cod northeastward the ice-sheet at its greatest extent and during a considerable part of its time of recession terminated in the ocean. In the interior of the continent, too, it was bounded during its recession by vast glacial lakes, filling the basins that are now partly occupied by the great lakes of the St. Lawrence, Nelson, and Mackenzie rivers. During six summers of field-work in examination of the shore lines, deltas, and bed of Lake Agassiz, the largest of these glacial lakes, I have carefully studied the effects attributable to the influence of this lake in the deposition of the drift, comparing its area, the valley of the Red river of the North, with other portions of Minnesota, South Dakota, North Dakota, and Manitoba, which were land surfaces during the departure of the ice. Other glacial lakes of smaller size in these states and Canadian province have also come under my observation, besides portions of the drift deposited in the glacial precursors of the Laurentian lakes; and on the Atlantic coast I have made a detailed examination of the marine drift of southeastern New Hampshire. The more southern parts of the New England seaboard which I have similarly examined, including the coast from Boston to Plymouth, Cape Cod, Nantucket, Marthas Vineyard, the Elizabeth islands, Block island, and Long island, appear to me to have stood at their present height or somewhat higher during the maximum extension and the recession of the last ice-sheet.

Upon all the areas thus studied by me where the ice-sheet was bordered by great lakes or the sea, tracts of stratified sediments, as deltas of gravel, sand, and silt, and somewhat more extensive deposits of finer silt and clay, are found; and their distribution shows them to have been chiefly brought into these bodies of water by rivers flowing down from the melting ice. But a large portion of the englacial drift, corresponding to that which elsewhere fell as wholly unstratified till on land areas, was received from the receding ice into these lakes or the sea with little change, being allowed to fall to their bottom only very slightly modified by water action. Within the area of Lake Agassiz and the other associated glacial lakes very extensive tracts, probably half or a larger part of their whole extent, have a surface of till which differs from its characters on the adjoining tracts that were land during the ice retreat in having usually slight traces of stratification within the five to fifteen feet of the upper and englacial till, and in having a more smooth and even contour.

Bowlders, gravel, sand, and clay are mingled in this englacial till in the same proportions as on the country outside these glacial lakes. There was generally no noteworthy transportation of bowlders or other drift by ice floes or bergs on these lakes; nor was the fine clayey part of the englacial drift washed away in any noteworthy amount from the submerged and melting and receding ice-margin by wave action, which would have covered the till in front of the ice-sheet with beds of silt. Instead, the englacial and finally superglacial drift that escaped the stream erosion

of the drainage from the glacial melting sank through the water to the bottom as the ice gradually withdrew, and exhibits essentially the same characters as on areas that were land, excepting its usually obscure traces of stratification and its smoother surface.

Remarks were made upon the paper by Robert Hay.

The following paper was read:

EFFECTS OF DROUGHT AND WINDS ON ALLUVIAL DEPOSITS IN NEW ENGLAND.

BY HOMER T. FULLER.

For twenty years or more I have been watching with much interest some slow changes of the surface of terrace formations in the valleys of New England rivers. The large predominance of granites, gneisses, and crystalline schists in northern New England east of the Green mountains has brought it about that the material ground up and deposited in these river valleys, both by glacial and river agencies, is chiefly quartz sand. On these terraces vegetation must have been very slow in getting a foothold. First, creeping vines, like the strawberry or low running blackberry or shrubs of diminutive size, may have advanced under the shade of larger shrubs and trees which bordered the water-courses and which gradually, too, climbed the slopes and occupied the plateaus. At all events, we know that these terraces in the valleys of the southwestern part of the territory mentioned were once covered with a magnificent growth of pine and elm and chestnut; that in the central region, even on these sandy soils, the maple and poplar and sometimes even the hemlock and beech thrived, and that farther northward the spruce grew everywhere. Now, however, portions of these terraced slopes are becoming absolutely desert, as bare of any vegetation as are the tracts of the African desert westward from the meadows of the Nile.

The object of this paper is to direct the attention of this Society first to the facts, as illustrated specially by one or two localities which are typical, and secondly to the causes as determined by long continued observation.

As might be presumed, the tracts most affected are above the reach of river overflow and where glacial erosion must have provided the material which was in the epochs following more finely pulverized and then separated by running streams. One of the best illustrations is presented in the valley of the southern branch of Sugar river, a tributary of the Connecticut, in the towns of Lempster, Goshen, and Newport, New Hampshire. This valley is a section of what in the later Glacial and early Champlain epochs must, if I mistake not, have been first a continuous stream of ice and then a broad river from almost under the shadow of Moosilauke mountain, in Grafton county, to near the Massachusetts border, if not, indeed, through to Connecticut. The proof is found in the continuous valley that extends nearly from north to south throughout this extent, and which lies west of Monadnock, the Sunapee range and Kearsarge, in Wilmot, and east of Grantham and Croydon mountains and the high hills of Unity, Lempster, Alstead, and Surry; and, secondly, in the height of terrace formations above and near the sources of the several streams which now drain the various sections of this longitudinal depression. In Lempster, for example, these terraces are twenty to forty feet above the sources of Cold river,

which flows southward, and Sugar river, which flows northward, and are found yet within a half mile of the glacial moraine which is the watershed between them.

These terraces were in the early part of the present century all clothed with forests. Some of them have been cleared and all of them cultivated within forty or fifty years. Later they were given up to pasturage, and in the course of fifteen years after I began to notice that the rounded slopes of these sugar-loaf hills on the southwestern sides began to lose their green, and bare sand appeared. Then the sand began to drift, generally toward the southeast, until in some spots acres were denuded of vegetation and other acres were covered three, four, and five feet in depth by the drifted sand. The work of destruction has continued until considerable parts of large farms are now worthless. The phenomena are confined to grassed lands, either mown or pastured. They cannot be caused by the action of water chiefly, because the beginnings of these changes are neither in ravines nor on the sides of ravines, unless, perchance, a slope is toward the south or southwest, but on the swells of the slopes.

The process appears to be this: First, the pasture is fed off or the field mown until the humus or organic matter in the soil, which is always thin, is exhausted or nearly so. The roots of the herbage are feeble and shallow. By and by a dry season occurs, and on the south-southwesterly slope, where the sun's rays strike almost vertically in the hottest part of a summer day, the grass dries up root and branch. The next spring these very spots lose more quickly than others the snow as it melts under the sun. Then the winds that follow in the months of March and April, generally in fair weather blowing from the west or northwest, cut out, as they strike the surface at a very slight angle, the dry sand and transport it to the nearest lower spot to the leeward. Sometimes the drift has gone across highways or through double fences of open rails or boards; sometimes, indeed, the sand has blown over the higher crest of the ridge and been deposited on ground more elevated than that whence it came. My observations of this denudation and defloration of fine silicious soils have covered the valleys of the Androscoggin and Saco rivers in Maine and New Hampshire, of the Merrimack and Connecticut and their tributaries in New Hampshire, Vermont, and Massachusetts. But I have noticed the beginnings, less marked, of the same kind of destruction of vegetation in southern New York on the headwaters of the Alleghany river, and in northeastern Pennsylvania on Oil creek, though these are comparatively newly cleared regions. For these bared knolls one must look on the eastern or northern sides of valleys and for the slopes that dip a little west of south. The three causes, as I have already intimated, are the shallowness or exhaustion of the soil, drought, and wind. Unless in some way counteracted. the "old fields" of the north may yet, if not in extent yet in desolation, vie with the "old fields" of the south. The only remedy is fertilizing and sheltering the bared spots, planting trees to the windward, abandoning grazing, and letting the forests again as of old occupy and reclaim and enrich in nature's own way the areas which continued cropping has exposed to waste by drought and varied erosion.

The last paper was as follows:

A DEEP BORING IN THE PLEISTOCENE NEAR AKRON, OHIO.

BY E. W. CLAYPOLE.

The preglacial geography of the northern part of Ohio has been so largely obscured by the mantle of glacial material deposited upon it that its restoration is attended with much difficulty. That some communication existed whereby the waters flowed into Lake Erie from a greater distance to the southward than is now the case has long been believed. A communication between the Cuyahoga and Tuscarawas rivers seemed to be rendered necessary by the physical geography of the region. At present the watershed passes about three miles south of Akron; but it is soon evident to the glacialist, and indeed to the observer if intelligent, though having no special knowledge of geology, that the great preglacial valleys which cross the country cannot have come to a sudden end at the present watershed, but must have continued to some distance southward. It has been generally assumed that this channel lay through the city of Akron, where is now a deep valley apparently forming a connection between the valleys of the Tuscarawas and the Cuyahoga. The depth of this valley to rock has never been proved, but wells have been sunk in the gravel which fills it to 150 feet or more without reaching bottom.* This gravel is the deposit of the retreating ice-sheet, and lies in great quantity south of Akron between the two lobes of the glacier which covered this part of the state. It is therefore postglacial in date.

Several circumstances, however, which cannot here be detailed combined to induce the belief that this channel did not at any time form a link of communication between the valleys of the present Cuyahoga and Tuscarawas. The narrowness of the channel in which the latter river now flows along part of its course is sufficient proof that it is not very deep, though undoubtedly preglacial. Accordingly, it was desirable to find some other way in which the water from the south could have found its way to Lake Erie through the Cuyahoga.

To the west of Akron, at the distance of about three miles, lies a wide swamp leading south from the Cuyahoga to the Tuscarawas valley, and to this my attention was directed some years ago, but no data could be obtained concerning it; all indications were in favor of a buried channel of considerable depth through which the long-sought passage might be found. During the winter of 1890, however, an Akron firm determined to put down a deep well in search of brine. Fortunately for the geologist, they chose nearly the middle of the valley above mentioned. Supposing that there would be some depth of soft material, the contractor obtained 100 feet of 8-inch pipe to be driven. A second lot followed, and a third, nor was it until nearly 400 feet had been driven (389) that the rock was at length reached.

This result, so different from expectation, changed the views previously entertained regarding the preglacial drainage of the district and revealed the true level of connection between the two above-mentioned rivers. Evidently the southern waters had come north, not through Akron, but through this newly revealed valley, whose bottom five miles south of Akron was now found to lie on the present level of Lake Erie. So deep a preglacial channel close to the watershed of the continent

*From one of these wells, at the depth of about 150 feet, the sand-pump brought up with the gravel a flint arrow-head.

indicated a considerable southward extension of the system of drainage, the extent of which is yet to be determined.

This preliminary note is not the occasion for further extension of the subject, but it may be remarked in conclusion that the valley above described is not, as that through Akron, filled with gravel, but with the same fine silt, mingled with some sand, which was described in the author's tract upon the Cuyahoga valley * as filling the glacial "Lake Cuyahoga" and being the deposit of its icy waters. This silt maintains a nearly flat surface, rising almost to the level of the watershed at Summit lake.

This discovery has, moreover, enabled the author to ascertain more exactly than was previously possible the outlet of this Lake Cuyahoga. Its waters extended southward along the swamp above mentioned until they were confined between the western wall of the preglacial valley and the moraine which gradually extended westward, and so narrowed it that at present there is only room a few miles farther southward for the exit of the present Tuscarawas, the canal, and the railways. This overflow or "col" is only a few feet below the level of the summit, and to all appearance the glacial lake that occupied it was nearly filled with this fine deposit during the retreat of the ice.

This paper was discussed by Edward Orton and Frank Leverett.

The Society reassembled in general session.

The following resolutions, offered by C. R. Van Hise, were unanimously adopted:

Resolved, That the Geological Society of America return sincere thanks:

First. To the officers of the Columbian University for their kindness in tendering the use of their buildings to the Society.

Second. To the local committee, Mr. Bailey Willis and Dr. George P. Merrill, who have, by their careful and painstaking preparations, contributed so largely to the comfort of the members of the Society and to the success of the Society's meetings.

It was also moved and voted that the thanks of the Society should be conveyed to the foreign visitors for their presence at the meetings and the papers which they had presented.

Acting President Gilbert then made some announcements relating to the International Geological Congress, receptions, etc., and, after a few appropriate remarks, declared the summer meeting of the Society adjourned.

*See "The Lake Age in Ohio" (R. Clarke & Co., Cincinnati), for further details on this subject.

The following Fellows were in attendance at the meeting:

George F. Becker.
John C. Branner.
Garland C. Broadhead.
Samuel Calvin.
Henry Donald Campbell.
T. C. Chamberlin.
J. H. Chapin.
Clarence Raymond Claghorn.
William B. Clark.
Edward W. Claypole.
Theodore B. Comstock.
Edward D. Cope.
Charles Whitman Cross.
Henry P. Cushing.
Nelson H. Darton.
Frederick P. Dewey.
Edward V. d'Invilliers.
Edwin T. Dumble.
George H. Eldridge.
Samuel F. Emmons.
Herman L. Fairchild.
Moritz Fischer.
Albert E. Foote.
Homer T. Fuller.
Grove K. Gilbert.
Arnold Hague.
James Hall.
Robert Hay.
Eugene W. Hilgard.
Robert T. Hill.
Charles H. Hitchcock.
Joseph A. Holmes.
Horace C. Hovey.
Edwin E. Howell.
Joseph P. Iddings.
Joseph F. James.
Lawrence C. Johnson.
James F. Kemp.
Charles R. Keyes.
Frank H. Knowlton.
Alfred C. Lane.
Andrew C. Lawson.
Joseph LeConte.
Frank Leverett.
Josua Lindahl.
W J McGee.
Othniel C. Marsh.
Frederick J. H. Merrill.
George P. Merrill.
Thomas F. Moses.
Frederick H. Newell.
Edward Orton.
Richard A. F. Penrose, Jr.
William H. Pettee.
J. W. Powell.
William North Rice.
Charles W. Rolfe.
James M. Safford.
Rollin D. Salisbury.
Nathaniel S. Shaler.
Eugene A. Smith.
J. W. Spencer.
John J. Stevenson.
Ralph S. Tarr.
Asa Scott Tiffany.
James E. Todd.
Edward O. Ulrich.
Warren Upham.
Charles R. Van Hise.
Charles D. Walcott.
Lester F, Ward.
Charles A. White.
David White.
Israel C. White.
Robert P. Whitfield.
George H. Williams.
Henry S. Williams.
J. Francis Williams.
Bailey Willis.
Horace Vaughan Winchell.
Newton H. Winchell.
Arthur Winslow.
John E. Wolff.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 153-172, PLS. 3-5

PRELIMINARY NOTES ON THE DISCOVERY OF A VERTEBRATE FAUNA IN SILURIAN (ORDOVICIAN) STRATA

BY

CHARLES D. WALCOTT

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP 153-172, PLS. 3-5 MARCH 15, 1892

PRELIMINARY NOTES ON THE DISCOVERY OF A VERTEBRATE FAUNA IN SILURIAN (ORDOVICIAN) STRATA.

BY CHARLES D. WALCOTT.

CONTENTS.

HISTORY OF THE DISCOVERY.

The first discovery known to me of lower Paleozoic fossils in the vicinity of Canyon City, Colorado, was made in 1887 by Mr. S. F. Emmons, of the United States Geological Survey. The collection included two species of lamellibranch shells and one species of gasteropod. After examining the specimens, I requested Mr. Emmons to have a larger collection made from the same horizon, as the species indicated an unrecognized Paleozoic fauna in Colorado. Mr. T. W. Stanton was employed by Mr. Emmons to collect from the sandstones and limestones above the Archean, and a collection was sent in by him accompanied by a sketch of several sections. About the same time Mr. I. C. Russell, of the Geological Survey, while stopping at Canyon City, collected from the lower sandstone a number of specimens of *Lingula* and several portions of the calcified covering of what is now considered to be the chordal sheath of a fish. The preliminary

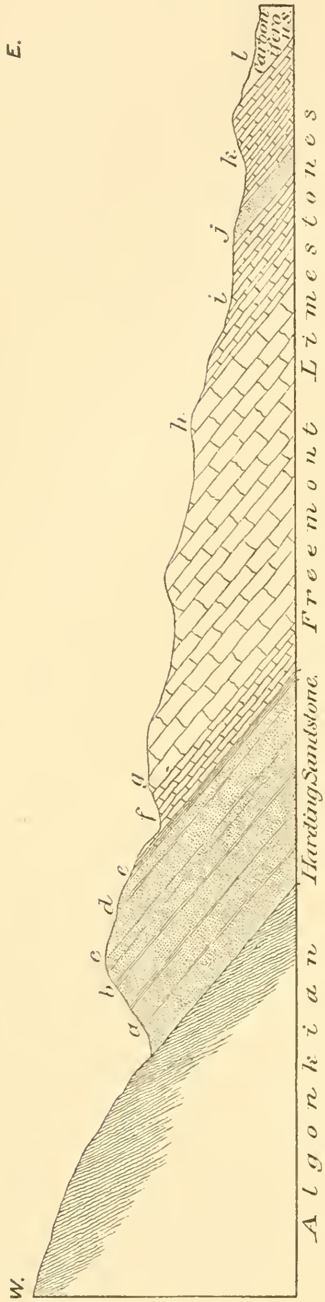


FIGURE 1.—*Diagramatic Section of the Canyon City Silurian (Ordovician) Rocks.*

a — Lowest fossiliferous bed of the Harding sandstone; *b c* — Shaly beds in which fish remains are abundant; *d* — Bed in which the Harding sandstone quarry is located; *e* — Shales above the sandstone; *f* — Limestone at base of Fremont limestone, in which the Trenton fauna is abundantly represented; *g h* — Lower impure limestone; *i* — More or less pure limestone with a few fossils; *j* — Sandstone parting; *k* — Upper horizon of the Trenton fauna; *l* — Carboniferous limestone.

examination of the collection obtained by Mr. Stanton proved the presence of the Trenton fauna in the limestone series above the sandstones. When examining a small fragment of sandstone upon which some lamellibranch shells occurred I discovered upon the lower side what appeared to be fragments of placoderm fish plates. Mr. Stanton was then requested to make a larger collection from the sandstone and to carefully review the stratigraphy of the section. This he did, and from his stratigraphic sections it was evident that the fish remains occurred beneath an invertebrate fauna having a Trenton facies, and an examination of the material disclosed the presence of a large number of plates of placoderm fishes of the types of those of the lower Devonian fauna.

Owing to the great interest of the discovery, and in order to make myself fully acquainted with the succession of the strata and mode of occurrence of the faunas before it was announced, I went to Cañon City in December, 1890, and studied the section in detail and collected largely from the lower sandstone and the immediately superjacent limestone. Mr. Stanton's stratigraphic sections were verified, and the débris was cleared away at critical points so as to photograph the

contact of the sandstone with the subjacent pre-Paleozoic rocks and with the superjacent shales and limestone; views were also obtained of the entire section from this point to the overlying Carboniferous limestone. After my return a brief notice of the presence of an icthyic fauna near Canyon City, Colorado, in association with an Ordovician fauna was read before the Biological Society of Washington on February 7th, 1891.

Description of the Locality.

Canyon City, Colorado, is situated near the southwestern shore of a bay of early Silurian (Ordovician) and probably also of pre-Cambrian time. The outcrop of pre-Cambrian rocks of the Rocky mountain front breaks away south of Pikes peak and sweeps with a broad inward curve to the westward, and thence southeastward past Canyon City before extending eastward to the meridian of Pikes peak. Along the central part of the western shore of this bay sediments were deposited in Silurian (Ordovician) time that at present form massive beds of sandstone and limestone extending several miles northward and southward on the flanks of the pre-Cambrian or Algonkian rocks west and northwest of Canyon City. The valley of the Arkansas river cuts the outcrop a mile west of the town and erosion has removed it in places, but it is practically continuous for ten miles north of the river, and isolated outcrops occur three miles southward toward and into Webster park. The typical section was measured in the immediate vicinity of Harding's quarry, which is about one mile northwest of the state penitentiary at Canyon City.

The Harding Quarry Section.

The section begins near a spring a little way west of the Harding sandstone quarry, and is carried on the strike of the beds so that it terminates nearly a mile north of the quarry. This is done in order to secure contacts from layer to layer all the way from the base to the summit. The basal bed of sandstone rests unconformably upon Algonkian bedded gneiss and micaceous schists that dip to the eastward at high angles, 60°–75°. The succession is as follows:

	Feet.
1. *a*—Coarse, light gray sandstone	5
b—Compact thinly bedded reddish and gray sandstone passing into a gray and more massively bedded somewhat friable sandstone that changes, at 25 feet up, into a purplish-tinted somewhat coarse friable sandstone (strike, N. 10° E. (mag.); dip, 40° E.)	33

Fossils.—A few scattered fish scales were noticed in the purple beds and *Lingula attenuata*, Salter (?), 20 feet from the base. The beds are penetrated by an immense number of annelid borings, and the surfaces of the purplish-tinted layers are often

Page.

a network of the casts of the borings. On the southern side of the Arkansas river, two miles south of the section, there were found in a stratum 20 feet above the Algonkian rocks numerous lamellibranchs, a few gasteropods, and numerous fragments of the plates and scales of placo-ganoid fishes.

c—Reddish-brown sandy shales that are partially calcareous in some layers 7

Fossils.—Fish plates in great abundance and, in the calcareous layers, *Orthoceras multicameratum*, Hall (?), *Beyrichia* (like *B. fabulites*, Conrad), and several species of lamellibranchs (see list, page 158).

d—Massively bedded gray and reddish sandstone, with thin irregular beds of reddish-brown sandy shale in the lower portion 20

Fossils.—Fish plates and scales of fish are numerous in the lower portion and also in a reddish-brown capping of the massive bed in which the Harding quarry is located. The supposed chordal sheaths occur scattered through this bed and also more rarely in *b*, *c* and *e*.

e—Fine-grained argillaceo-arenaceous shale 3
Gray and buff sandstone 7
— 10

f—Coarse purplish-tinted sandstone in several layers, with gray layers above 11

Fossils.—Plates and scales of fish.

Total sandstone 86

Observations on the Harding Sandstone Series.—The lower bed is a shore-line deposit following the advance of the sea upon the land; it is formed of coarse grains of quartz and small quartz pebbles imbedded in a fine arenaceous matrix. The succeeding layers of sandstone have more or less calcareous matter in the matrix. Their contained acephalous shells, drift-worn plates and scales of fishes, and the vast number of casts of annelid borings, all prove the littoral origin of the sediments. The fish plates and scales are scattered more or less throughout the beds, but they are very abundant in four principal zones, viz, *c* of the section; near the base, and again near the summit of *d*; and at the summit of *e*. In *c* they are commingled with remains of *Orthoceras* and with acephalous mollusks and gasteropods. The closing deposit of the sandstone series is formed of a coarse drifted sand, containing numerous fragments of larger fish plates than those below. The change to the succeeding shaly beds is abrupt, and apparently due to the deepening of the water and the cessation of arenaceous deposits.

2. Red and purple fine-grained argillaceo-arenaceous shale 2–4

Fossils.—Rolled and worn fragments of fish plates occur in the lower portion.

3. Gray silicious magnesian limestone, somewhat ferruginous in the lower portion. Locally, this decomposes to a reddish, friable rock and soil; the entire mass above 25 feet from the base weathers into rough, irregular cliffs with numerous shallow caverns and holes of various sizes and forms 170

Page.

Fossils.—The lower layers are, in places, made up largely of the casts of corals and mollusks, but well preserved specimens are rare. Corals were observed in abundance in the lower 10 feet of the limestone on the northern side of the road leading from Canyon City to Parkdale, a little east of where it enters on the pre-Paleozoic rocks. In the lower three feet at the Harding quarry and immediately toward the north there have been collected the species mentioned in the list, pages 159, 160.

4. *a*—The upper portion of 3 passes into a hard, compact, light-colored limestone.. 45

Fossils.—*Zaphrentis* and fragmentary casts of gasteropods.

b—Dark reddish-brown sandstone.................................. 10

c—Compact, hard light gray limestone breaking into angular fragments and with a band of purple and gray calcareo-arenaceous shale at the base.. 45

Fossils.—A large and varied fauna occurs of a Trenton type (see list, pages 161, 162).

5. Impure variegated banded limestone with interbedded sandstones and argillaceous beds.. 15–30

Fossils.—*Spirifera rockymontana*, *Athyris subtilita*.

Observations on the Fremont Limestone Series.—The line of demarkation between the upper beds of the Silurian (Ordovician) and the superjacent limestones in which Carboniferous fossils occur is not strongly defined, although it represents a long period of non-deposition and a great time break. The Carboniferous limestones are sometimes brecciated and lithologically unlike those below. No traces of the Silurian and Devonian groups have been obtained.

The bed of shale (number 2 of the section) is very persistent along the six miles of outcrop examined. Fragmentary fish plates and scales occur in the lower portion, but they were not observed in the upper part nor in the superjacent limestones. The shale appears to include the closing deposit of the ichthyic fauna in this region.

The basal layer of limestone resting on number 2 is in many places almost entirely made up of casts of fossils that crumble into a red dust when the rock is broken. At a few localities they are better preserved, and 54 species in all were collected. Traces of fossils occur all the way through the 170 feet of impure limestone, but it is not until the upper portion of number 4 of the section is reached that well-preserved specimens occur. In number 4*c*, 57 species have been recognized, only 7 of which occur in number 3.

The character of the sediments from the basal sandstone to the uppermost layer of limestone beneath the Carboniferous breccia indicates that they were deposited in a bay or interior sea that was protected from the open ocean. After the epoch of the accumulation of the beach sands and

shales the water deepened, the ichthyic fauna disappeared, and the typical invertebrate fauna of the Trenton epoch of New York flourished and was imbedded in the calcareous sediments. The study thus far made of the upper portion of the Silurian (Ordovician) section and the Carboniferous strata has not shown the presence of Silurian or Devonian strata. If deposited in this region they were eroded away by the Carboniferous sea. The study of the breccias resting on the Carboniferous, or forming its upper portion, may possibly throw some light upon this interval. Mr. Stanton considers that the detailed sections give evidence of at least two, and perhaps three, periods of upheaval and erosion from the Silurian (Ordovician) to the Trias, inclusive.

The Invertebrate Fauna.

Harding Sandstone.—The invertebrate fauna of the sandstone series is molluscan with the exception of one species of crustacean. As would be expected in such a deposit, the acephalus mollusks number more than one-half of the species of the entire fauna. The largest number of specimens were collected in *b* and *d* of the section, figure 1. The fauna has been partially identified and will be more thoroughly studied when the collections now being made are available. The genera and species recognized are as follows:

BRACHIOPODA.

Lingula, like *L. attenuata*, Salter, and *L. belli*, Billings.

LAMELLIBRANCHIATA.

Modiolopsis, like *M. trentonensis*.
" 3 sp. undet.
Cypricardites, like *C. ventricosa*, Hall.
" like *C. rotundata*, Hall.
Cypricardites, 2 sp. undet.
Orthonota, sp. undet.
Tellinomya, 3 sp. undet.

GASTEROPODA.

Helicotoma, sp. undet.
Pleurotomaria, sp. undet.
Murchisonia, sp. undet.

CEPHALOPODA.

Orthoceras multicameratum, Hall.
Cytoceras, sp. undet.

CRUSTACEA.

Leperditia, type of *L. fabulites*, Conrad.

Summary.

	Genera.	*Species.*	*Species identified.*
Brachiopoda	1	1	1 (?)
Lamellibranchiata	4	12	3
Gasteropoda	3	3	0
Cephalopoda	2	2	1
Crustacea	1	1	1
Total	11	19	6
Recurrent above	9	1	1
Limited to	2	18	5

The presence of forms apparently identical with *Lingula attenuata*, *Modiolopsis trentonensis*, *Cypricardites ventricosa*, *C. rotundata*, *Orthoceras multicameratum*, and *Leperditia fabulites* leads to the conclusion that the Trenton fauna is represented, and (from the known range of those species in the New York section) that the fauna is lower Trenton or that of the Black River and Birdseye limestones. This is further sustained by the occurrence of the Trenton fauna higher up in the section.

Only one species (*Orthoceras multicameratum*) is known to range upward into the limestone, although it is probable that some of the species of lamellibranchs may be found to be identical in the two formations.

Fremont Limestone.—The fauna of the base of the limestone, number 3 of the section, extends through some earthy and semicrystalline layers ranging from 4 to 10 feet above the upper bed of sandstone. It is large and varied, and contains the following genera and species, as determined in the preliminary study of the fauna:

PROTOZOA.

Stromatopora, sp. undet.
Receptaculites oweni, Hall.
Receptaculites, sp. undet.

ACTINOZOA.

Streptelasma, sp. undet.
Zaphrentis, sp. undet.
* *Halysites catenulatus*, Linn.
Monticulipora, sp.?
Phyllopora, sp. undet.
* *Columnaria alveolata*, Goldfuss.
Favosites, sp. undet.
Heliolites, sp.?

ECHINOZOA.

Echinosphærites, n. sp.
Glyptocrinus, sp. undet.

BRACHIOPODA.

* *Strophomena alternata*, Conrad.
* *Streptorhynchus filitextum*, Hall.
Orthis tricenaria, Conrad.
" sp. undet.

BRACHIOPODA—Continued.

Streptorhynchus sulcatum, Verneuil.
" sp. undet.
Orthis biforata, Schlotheim.
" *flabellum*, Sy.?
* " *subquadrata*, Hall.
**Rhynchonella capax*, var. *increbescens*, Hall.
Rhynchonella dentata, Hall.
Camarella, sp. undet.

LAMELLIBRANCHIATA.

Ambonychia bellastriata, Hall.
" 2 sp. undet.
Modiolopsis plana, Hall.
Modiolopsis, 2 sp. undet.
Cypricardites, 2 sp. undet.
Tellinomya, sp. undet.

GASTEROPODA.

Metoptoma, sp. undet.
Helicotoma (casts of the interior).
Murchisonia tricarinata, Hall.
" 2 sp. undet.
Cyclonema bilex, Conrad.
" *percarinata*, Hall?
" sp. undet.
Bellerophon bilobatus, Sow.

CEPHALOPODA.

**Endoceras proteiforme*, Hall.
Ormoceras tenuifilum, Hall.
" *crebriseptum*, Hall?
Orthoceras vertebrale, Hall.
" *multicameratum*, Hall.
Gomphoceras powersi, James?
" sp. undet.
Cytoceras, 2 sp. undet.
Lituites, sp. undet.

TRILOBITA.

**Asaphus*, like *A. platycephalus* (fragment of pygidium).
Illænus crassicauda, Wahlen.
* " *milleri*, Billings.

Summary.

	Genera.	*Species.*	*Species identified.*
Protozoa	2	3	1
Actinozoa	8	8	2
Echinozoa	2	2	0
Brachiopoda	5	12	9
Lamellibranchiata	4	9	2
Gasteropoda	5	9	4
Cephalopoda	6	9	6
Trilobita	2	3	2
Total	34	55	26
Recurrent above	19	9	9
Confined to	15	46	17

Of this fauna *Halysites catenulatus*, *Columnaria alveolata*, *Strophomena alternata*, *Streptorhynchus filitextum*, *Orthis subquadrata*, *Rhynchonella capax* var. *increbescens*, *Endoceras proteiforme*, *Asaphus platycephalus* (?), and *Illænus milleri* extend up to the next strongly marked fossiliferous horizon, 215 feet above. Without exception, all these species have an extended vertical range in the Silurian (Ordovician) strata either in North America or Europe. The fact that 25 of the 27 identified species are identical with those of the Trenton fauna of Wisconsin and New York is sufficient to locate the horizon in the Ordovician fauna. *Halysites catenulatus* is not known from the Trenton zone elsewhere in America: but in Wales it ranges through the Bala and the subjacent Llandeilo. *Orthis flabellum* is also a Bala species. There is nothing among the unidentified species to indicate a higher horizon than the Trenton of the New York section.

Scattered and fragmentary fossils occur in the 225 feet of superjacent limestone; but it is in the beds 225 to 245 feet above the Harding sandstone that the fauna is best preserved. From this zone the following species have been collected:

ACTINOZOA.

Streptelasma corniculum, Hall.
" 2 n. sp.
Columnaria alveolata, Goldfuss.
Favosites gothlandicus, Lamark.
Pleurodictyum, n. sp.
Halysites catenulatus, Linn.
Monticulipora, 2 sp.?

ECHINOZOA.

Loose plates or segments of crinoidal columns.
Cyclocrinus, sp.?

BRACHIOPODA.

Leptæna sericea, Sowerby.
" sp. undet.
Strophomena alternata, Conrad.
" *alternata* var. *nasuta*, Conrad.
Strophomena deltoidea, Conrad.
Streptorhynchus filitextum, Hall.
" *nutans*, James.
Streptorhynchus planoconvexus, Hall.
" *planumbonus*, Hall.
" *subtentum*, Conrad (?).
Orthis subquadrata, Hall.
" *testudinaria*, Dalman (?).
Rhynchonella capax, Conrad.
" *capax* var. *increbescens*, Hall.

LAMELLIBRANCHIATA.

Pterinea, sp. undet.
Tellinomya dubia, Hall (?).
" *levata*, Hall (?).
" *nasuta*, Hall.
Tellinomya ventricosa, Hall.
Cypricardites, 3 sp. undet.
Modiolopsis faba, Conrad.
" sp.?

GASTEROPODA.

Metoptoma, sp. undet.
Helicotoma planulata, Salter.
" sp.?
Trochonema beachi, Whitfield (?).
Murchisonia milleri, Hall.
" *pagoda*, Salter.
Murchisonia, 3 sp. undet.
Subulites (?), sp. undet.
Bucania bidorsata, Hall.
" *buelli*, Whitfield.
Cyrtolites, sp. undet.

CEPHALOPODA.

Orthoceras annellum, Conrad.
" *junceum*, Hall.
Endoceras proteiforme, Hall.
Gomphoceras, sp.?

CRUSTACEA.

Leperditia, sp.?

TRILOBITA.

Ceraurus icarus, Billings.
" sp.?
Bathyurus (?), sp. undet.
Proetus (?), sp.?
Asaphus platycephalus, Stokes.
" *megistos*, Locke.
Illænus milleri, Billings.

Summary.

	Genera.	*Species.*	*Species identified.*
Actinozoa	6	9	4
Crinoidea	1	1	0
Brachiopoda	6	12	11
Lamellibranchiata	4	10	5
Gasteropoda	7	13	6
Cephalopoda	3	4	3
Crustacea	1	1	0
Trilobita	5	7	4
Totals	33	57	33

This fauna is distinctly of a Trenton facies, but as a whole it is upper Trenton or Lorraine rather than lower Trenton.

Recapitulation.—On assembling the faunas of the three fossiliferous zones, the distribution of genera and species is found to be as follows:

	Genera.	*Species.*	*Species identified.*
Harding Sandstone	11	19	6
Fremont Limestone (lower portion)	34	55	27
" " (upper portion)	33	57	33
	78	131	66
Recurrent	28	10	10
Total fauna	50	121	56

An analysis of the fauna will not be attempted at present, as the collections now being made will enlarge the data for comparisons, and the final study of the fauna will result in the identification of a greater number of species. I think sufficient data are given clearly to prove that the invertebrate fauna of the Harding sandstone corresponds to that of the lower Trenton of the New York section or the lower Bala of Wales. The fauna of the two limestones is to be compared to that of the middle and upper Trenton of America or the Bala of Europe. It is not to be expected that an absolute correlation can be made of all the genera and species common to the Colorado, Mississippi valley and New York sections. The vertical range of some genera and species will be found to vary, but as a whole the succession is the same in the several sections.

The discovery of so large and varied a fauna of Trenton facies is of great interest, irrespective of its bearing on the stratigraphic position of the ichthyic fauna. It clearly proves the continuation of the fauna of the Trenton sea from Wisconsin, Iowa and Missouri to the western side of the great interior sea.*

The range of *Halysites catenulatus* has hitherto been considered to be limited to the Niagara terrane of the American Silurian, and it has often been the sole means of identifying that horizon. With the extended range it is now known to have in the Ordovician fauna of Colorado we can speak less confidently of the stratigraphic horizon identified by its presence. In Wales and England it ranges from the Llandeilo through the Bala or Caradoc.

The Vertebrate Fauna.

General Character.—The evidence of the existence of vertebrates at this early epoch is limited to the plates and scales of ganoid fishes and what appears to be the ossified chordal sheath of a fish allied to the recent *Chimæra*. The latter correlation is based entirely upon the resemblance between the fossil form and the calcified chordal sheath of *Chimæra monstrosa*. This resemblance is too striking to be passed over, although there are certain differences that render it of less value in classification than at first appears. The *Holoptychius*-like scales and the *Asterolepis*-like plates are their own interpreters and prove their connection with the lower Devonian types with which they are compared. They are clearly the diminutive ancestral types of the great fishes that at a later date swarmed in the Devonian sea and left their remains in the classic "Old Red sandstone."

*Quite recently I received from Professor F. R. Carpenter *Maclurea logani* and *Endoceras annulatum* that were collected from a band of limestone beneath the Carboniferous of the Black Hills of South Dakota, thus establishing another outpost in the Trenton sea.

Mode of Occurrence.—The stratigraphic section shows the vertical range of the fish remains to be from about 20 feet above the base of the sandstone to its summit and one or two feet into the superjacent argillaceous shale; in all, 75 to 80 feet in the Harding quarry section. The horizontal distribution extends along some eight miles of outcrop west of Canyon City, and another locality was discovered 150 miles to the northwestward, by Mr. George H. Eldridge, on Cement peak, southeast of Crested butte, Gunnison county, Colorado. This locality is now under investigation.

In the Harding sandstone the fish remains are most abundant in a reddish, sandy shale that occurs in irregular bands at several horizons. They are also scattered irregularly through the more massive beds. This is the case with the chordal sheaths more than with the plates and scales. The latter usually occur in great numbers with only a few traces of the former, while in the massive sandstone the plates and scales are infrequent and the sheaths more or less abundant. The invasion of the sand in large quantity appears to have overwhelmed the *Chimæra*-like fish and acephalous mollusks, while the armor-plated fishes, gasteropods and cephalopods, escaped to subsequently perish and have their remains rolled about by the currents spreading the thinner and finer sandy layers. The acephalous mollusks and the sheaths occur in the latter, but less frequently. In the upper bed of coarse sandstone numerous plates and fragments of plates occur, but all are more or less injured by the trituration of the sand as they were rolled along with it. The same is true of the greater portion of the fish remains in all the shaly bands. As yet no bed has been discovered where the conditions were favorable to the preservation of the united plates or scales forming the armor of the fish.* The chordal sheaths show less evidence of abrasion, but no other portions of the same fish have been found with them.

The invertebrate fauna associated with the fish remains is largely molluscan and of sand-loving types. The exceptions to this are found in the shaly beds where the rolled fragments of gasteropods and cephalopods indicate transportation from a more congenial habitat. The numerous specimens of *Lingula* and of lamellibranch shells and the vast number of annelid borings in some portions of the sandstones indicate the conditions of the deposition of the massive layers, while the shaly bands denote the period of minimum deposition and maximum accumulation of the fragmentary fish remains and the rolled fragments of invertebrates.

Position in the geologic Series.—This has already been determined by the study of the invertebrate fauna. The fish remains occur at the horizon of the lower Trenton in America, or the relatively similar horizon, the lower Bala of Wales.

* A single specimen of *Astraspis desiderata* has been found since this paragraph was written (p. 167).

Notes on the ichthyic Remains.—Fishes have been found in the Ludlow rocks of the Silurian of England and in the Bloomfield sandstone of Pennsylvania in America, a horizon of the upper portion of the Onondaga salt group. Professor E. W. Claypole has also described certain minute spines which he considered might belong to an elasmobranch fish that he found in the Clinton terrane.* The evidence, however, is not conclusive, as they may belong to some crustacean.

It is to be noted that the middle Silurian forms thus far found belong to the two families Pteraspididæ and Cephalaspididæ, and that no representative of the great placoderms of the Devonian has been found in the true Silurian. In strong contrast to this the ichthyic fauna of the Harding sandstone appears to contain a characteristic representative of the Placodermata and Crossopterygea of the Devonian, and what appears to be a type of the Chimæroidæ. Serious objection will undoubtedly be made to the classification, as it is based entirely upon the characters of the dermal plates and scales. These, however, are so pronounced that the classification is tentatively adopted. The vertical range of the ichthyic fauna is extended downward from the middle (Upper) Silurian to the base of the Lower Silurian (Ordovician), and the conclusion is reached that the differentiation of vertebrates and invertebrates must have begun in Cambrian time.

Pending the investigation of the beds containing the fish remains and the collection of more material, it is not desirable to illustrate the invertebrate fauna or to do more than outline the characters of the fragmentary fish remains. For convenience of reference to the latter, names are applied to three of the most marked forms and illustrations are given of typical fragments of these forms. The classification is tentative.

Since some doubt was expressed, during the discussion, as to the true zoologic character of the dermal plates, microscopic sections were made of the tuberculated *Asterolepis*-like forms. These showed microscopic characters much like those found in the Devonian *Asterolepis*, and Dr. Otto Jaekel kindly offered to make a few sketches and write a brief note upon them.†

Descriptions of the Ichthyic Fauna.

CHIMÆROIDEA.

DICTYORHABDUS PRISCUS, N. GEN., N. SP.

This genus and species is based on a calcified chordal sheath that has some of the structural characters of the chordal sheath of *Chimæra mon-*

* Quart. Jour. Geol. Soc. London, vol. 41, 1885, p. 18.

† This note is appended as a part of Dr. Jaekel's discussion (pp. 168-170).

strosa, except that it is open below and gives rise on the sides to what appears to have been the support of the ribs. Further description will be given in a final paper.

The principal material upon which the genus and species are founded is illustrated on plate 3. Figure 1 is a side view of a portion of a rather large sheath. It shows the close transverse rings and the projecting lateral rib sockets or supports. Figure 2 is a view from above of a portion of the sheath shown in figure 1 to display the form and arrangement of the lateral rib sockets or supports. Figure 3 is an enlargement of the surface of a chordal sheath to show the characteristic network formed by the crossing of the two series of elevated, raised, curved striæ. It is considered that these represent the fibres of the sheath, while the vertical rings shown in figures 1 and 5 are the calcified rings. The fusion of the rings and the oblique fibers give rise to the continuous calcified sheath, as in *Chimæra monstrosa*. Figure 4*a* is a transverse outline of the chordal sheath to show that is was not closed on the ventral surface, and figure 4*b* is a transverse outline cutting across the lateral extensions or rib supports. Figure 5 represents a portion of a small chordal sheath, showing its flexible nature and indicating that the larger fish must have attained considerable size.

GANOIDEA.

Sub-order Placodermata.

Family Asterolepidida (?).

ASTRASPIS DESIDERATA, N. SP.

This type is represented by fragments of plates allied to those of *Asterolepis ornatus* of the Devonian.

The material upon which the species is founded is illustrated on plates 3 and 4. On plate 1 figure 6 shows the inner surface of a plate with a portion broken away so as to exhibit the base and transverse sections of the tubercles of the outer surface, and figure 7 represents the interior surface of a plate for comparison with figure 6. Figure 8 represents a fragment of a supposed ventral plate of the body, figure 9 a plate referred to the cephalic region, and figure 10 a small elevated tuberculated plate. Figure 11 shows the supposed inner surface of a plate similar to that represented in figure 10, and figure 12 the inner surface of a plate similar to that seen in figure 11. Figure 13 is a transverse section of a narrow, elongate plate, showing a cellular structure and the projecting tubercles. The latter expand at the summit into a round knob, the upper surface of which is cut by radiating striæ, so as to give it a star-like *Astra*-form

appearance. This is more clearly shown in figure 14, which is a side view of the knob-like *Astra*-form tubercle of the outer surface when unabraded. On plate 4 figure 1 represents a dermal plate with two raised tubercles and numerous small *Astra*-form tubercles, and figure 2 is the outer surface of a supposed lateral plate. Figures 3 and 4, plate 4, represent the outer surfaces of partially abraded plates.*

SUB-ORDER CROSSOPTERYGEA.

Family Holoptychiidæ.

ERIPTYCHIUS AMERICANUS, N. SP.

This species is based entirely upon the separated scales. It is not improbable that several species are represented in the material, the better preserved portion of which is illustrated in plate 4, figures 5 to 11. Figures 5 and 6 are broad scales, each showing the bearing surface or facet of the next anterior scale and the ornamented exterior surface. The latter has numerous elevated longitudinal lines upon it. Figure 7 is a fragment of a scale with irregular stellate surface ornamentation, and figure 8 another fragment of a scale of the same type. Figure 9 is a phase of surface ornamentation somewhat like that of figure 8, and figure 10 is an intermediate phase of ornamentation between that of figure 7 and those of figures 5 and 6. Figure 11 represents the interior of a narrow scale that shows the poriferous inner surface and, where broken away, the base of the elevated longitudinal lines of the outer surface.

Plate 5 illustrates the microscopic structure of the remains of both the species discriminated.

---

*During the fall of 1891, a portion of the head carapace of *Astraspis desiderata* was found in a very fine grained calcareous sandstone. It measures 73mm in length by 50mm in width at the posterior margin and 40mm toward the front. It is formed by the union of a great number of small plates, such as are illustrated on plate 3, figures 10–14. A median ridge formed of elevated, tuberculated plates extends from the posterior margin 43mm toward the front, very much as in the head shield of *Thyestes verrucosus*, Eichwald, from the Silurian rocks of the island of Oesel, Russia. A similar ridge occurs on each side that extends forward 28mm from the posterior margin: they are 13mm from the median ridge at the base and 9mm from it at their anterior termination. A marginal ridge occurs on each side of the specimen that is continuous with the margin so far as the latter is preserved. Directly in front of the median ridge a group of 12 plates having elevated centers are clustered around a central plate that rises at the center above the others. On each side of this cluster of plates a larger plate (4 x 6mm) occurs that has six elevated tuberculated points on it. Anterior to this there is a plate with two points and another with three. Over other portions of the carapace the plates have usually only a single elevation near the center. The small *Astra*-form tubercles occur on all the plates. The form of the portion of the carapace preserved and its appearance suggests the cephalaspian fishes of the Silurian of Russia, while the separate plates and *Astra*-form tubercles foreshadow the Asterolepidæ of the lower Devonian.—*March, 1892.*

DISCUSSION.

Professor Dr. ZITTEL: I consider the fossils exhibited by Mr. Walcott to be dermal plates and scales of fishes. They differ considerably from everything hitherto known from Silurian strata, and show a decided resemblance to *Asterolepis* and *Holoptychius* of the Devonian rocks. Microscopic slides are needed to show with certainty the osteoblasts and the peculiar structure of the dermal ossifications of fishes.

Dr. FREDERICK SCHMIDT: I agree with Professor Zittel that the fossils are undoubtedly fish remains.

Professor E. W. CLAYPOLE: Before we can admit the existence of fishes during so early a period as the earlier Silurian, it will be necessary to use every means to prove the ichthyic character of the remains, especially the study of microscopic sections.

Professor E. D. COPE: It is very doubtful whether the remains of crossoptergyian fishes occur at so low a horizon. I consider it essential that the skeleton should be found before deciding that fishes were present, as the dermal covering of the lower vertebrate is not a reliable character in classification.

Mr. WALCOTT: Microscopic sections are being made and will be fully described in a final paper. Moreover, Mr. S. Ward Loper is collecting material in Colorado at the present time that may add materially to our knowledge of the fauna.

Dr. OTTO JAEKEL: The remains in their exterior characters do not recall the fish remains known from the Upper Silurian, but rather those of the Old Red sandstone. The resemblance to the latter becomes still more striking for the reason that the two appear in the same kind of rock and in like condition of preservation; but on closer comparison of the two it appears that the agreement is by no means so great as would seem at first sight. The forms resembling each other cannot be identified. and the fauna here spoken of exhibits types of microscopic structure that are as foreign to the Devonian as to the upper Silurian. Still, this much seems certain: that the pteraspidae and acanthodians, dominating in the uppermost Silurian, are absent from this fauna; whereas, on the other hand, they ally themselves with the Devonian remains of Crossopterygea and placoderms and of true ganoids. Not a single fragment shows any resemblance with the placoid parts of the elasmobranchii.

* In response to an invitation from Mr. Walcott to discuss briefly the micro-structure of the fish remains, I may observe, as regards the histo-

* Note communicated after examining the slides made from the fossils.

logic state of preservation of the remains, it unfortunately leaves much to be desired. In a general way, the fossils show merely the coarser histologic structure, while the finer details are for the most part invisible. The material is in this respect somewhat in the same condition as the Devonian fish remains from the Old Red sandstone of Scotland, in which likewise the finer histologic details are usually not present, while in the remains from the Russian Devonian they are finely preserved. The state of preservation depends on the retention of the fine dentine and primitive tubules; and this again depends on their being filled with air or with a dark infiltrate. At times it is seen that in one part of the slides the fine canals are completely preserved, while in the other parts of the same preparation either (*a*) only single parts of the tubules are preserved or (*b*) the tubules are altogether invisible. In such case the outlines of the tubules are sometimes seen in oblique illumination. This is the case with our fish remains. The fine details are mostly invisible, but are preserved in some parts and may then be easily recognized with an oblique converging light. Add to this that all hard parts are more or less worn and probably changed in various ways by acids. This being premised, the micro-structure exhibits the following conditions:

Figure 1 of plate 5 shows a vertical section through a scale or a carapace fragment. In the upper part of the preparation there are seen tubercles of dentine (*D*), containing a pulp from which numerous dentine tubules run out. These are especially well preserved in part in the middle dentine tubercle, while the outlines of the pulp appear greatly corroded. These conditions are seen more distinctly in figure 2, in which two dentine tubercles lying side by side are enlarged about 70 diameters. Here not only are the dentine tubules seen well preserved, but the outline of the pulp, too, is unchanged. It is furthermore important to note in them the concentric lamination, which appears in primary connection with the dentine tubules. The concentric lamellæ do not run in uniform curves, but arch independently between the dentine tubules, the curvature being directly inward. Toward the outside the lamellæ run more uniformly parallel to the surface. This concentric building up out of lamellæ appears with like distinctness in the dentine tubercle represented in figure 3, which in its outer form reminds one of a tooth. It also greatly recalls the teeth which are described by Rohon from the blue clay of St. Petersburg. There can hardly be any doubt that this concentric structure of the hard parts represents a low stage of development. At any rate, I believe that the most essential difference between the calcified hard parts of the lower animals and those of the vertebrates consists in this: that in the former growth took place only by apposition, and that

they show merely a stratification of lamellæ lying one above the other, while in vertebrates growth takes place from within by special cells, odontoblasts or osteoblasts. The fossil proofs for the former are the dentine tubules; for the later, the outlines surrounding the osteoblasts. The former we saw in the dentine tubercles, figures 1–3; the latter are distinctly recognized in figure 4, which is enlarged to about 350 diameters. It plainly shows small, irregularly bounded hollow spaces with ramifying and anastomosing shoots. These I can only regard as true osteoblasts, peculiar to the hard dermal parts of the ganoids, inclusive of placoderms. Their existence might at once be conjectured from the outer appearance of the remains. Of course only detailed investigation can show whether they exist in all the remains here described. In the cross-section shown in figure 1 they appear to be preserved in the lower parts, yet their state of preservation there is far less perfect, so that their existence can merely be designated as probable. Briefly speaking, the observations show the following facts:

1. The existence of undoubted dentine tubules proves beyond doubt that the remains, so far as they have been microscopically investigated, belong to vertebrates.

2. The occurrence of true osteoblasts distinguishes these hard parts beyond doubt from those of the elasmobranchii and relegates them to the division of the ganoids. Enamel could not be found in the specimens studied. On account of this and by the strikingly distinct concentric lamination in the dentine tubercles, the hard parts investigated indicate a low stage of development.

Professor JAMES HALL:* In reference to the invertebrate fossils shown me as coming in above the beds containing fish remains, I need only say that they have a general Lower Silurian facies and represent in their genera and species the fauna of the Trenton period, including Birdseye, Black river, and Trenton limestones. Some of them which were pointed out as coming from the higher beds as exposed in the section seem to me to be representatives of the Hudson River horizon; for example, *Orthis* (*Plasiomys*) *subquadrata*. The abundance and large size of the specimens of *Rhynchonella increbescens* or *R. capax* seem scarcely compatible with the strict limitation of the Trenton horizon. Comparing the lists of the species which have been made, I can have no hesitation in coinciding with the determinations, thus leaving no doubt whatever of the nature and age of the deposits.

* A note communicated to the author.

With regard to the fish remains I hesitate to express any opinion beyond this, that they have a remarkable similarity to Devonian forms. The nature and mode of aggregation of the material in which they are imbedded has a most decided Devonian aspect, and had they been presented to me without other evidence, I should not have hesitated in expressing my opinion as to their Devonian age.

Description of Plates.

Plate 3.

Figures 1–5.—Various views of the supposed chordal sheath referred to *Dictyorhabdus priscus*, n. gen., n. sp.

Figures 6–14.—Dermal plates of *Astraspis desiderata*, n. sp.

Plate 4.

Figures 1–4.—Outer surface of partially abraded plates referred to *Astraspis desiderata*, n. sp.

Figures 5–11.—Various views of dermal scales referred to *Eriptychius americanus*, n. sp. It may be that several species are represented.

Plate 5.

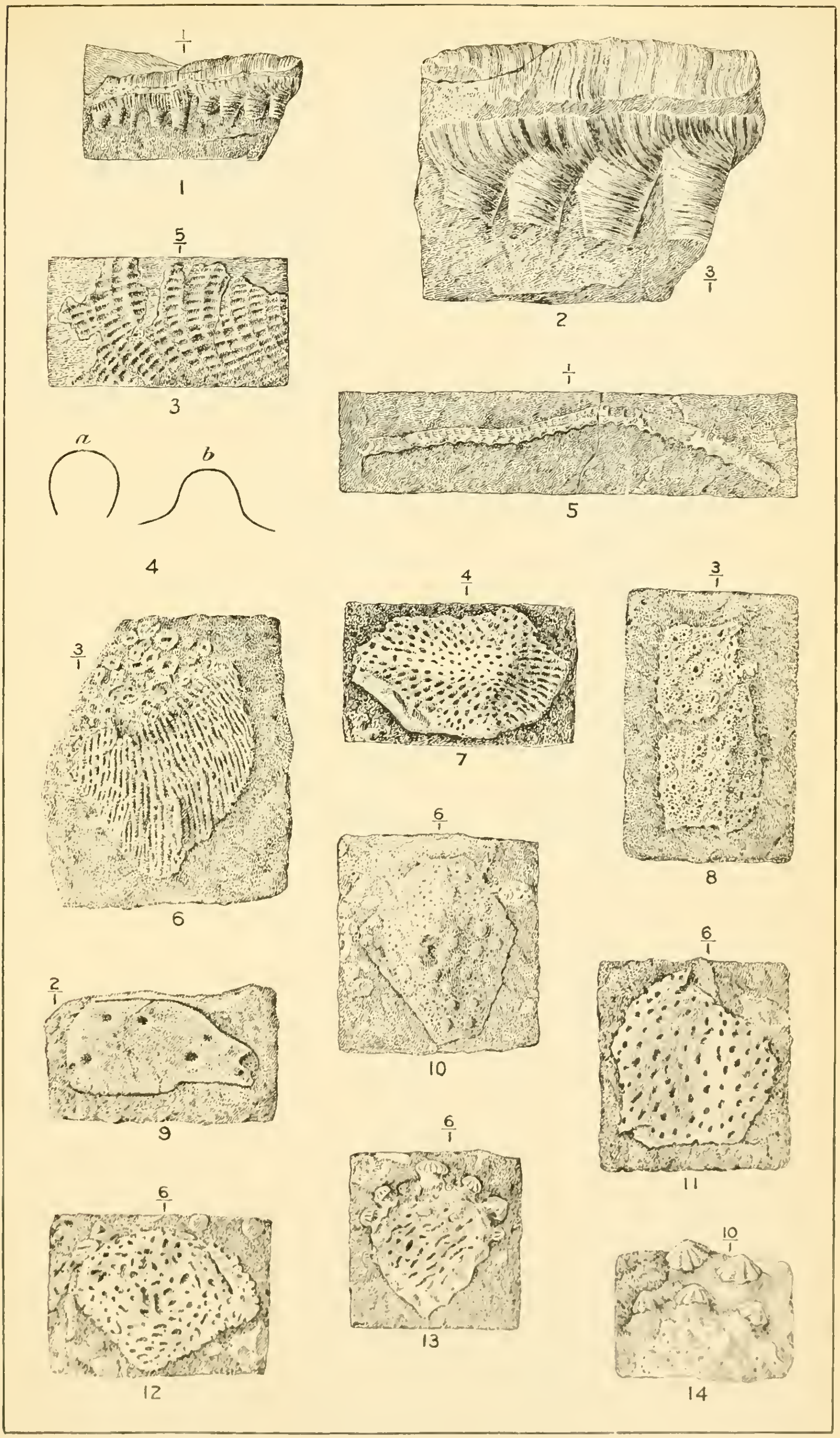
(*Greatly enlarged drawings to illustrate Dr. Otto Jaekel's remarks on the microscopic characters of the fossils.*)

Figure 1.—Cross-section through a plate with haversian canals (*V*), osteoblasts (*O*), and dentine tubercles (*D*).

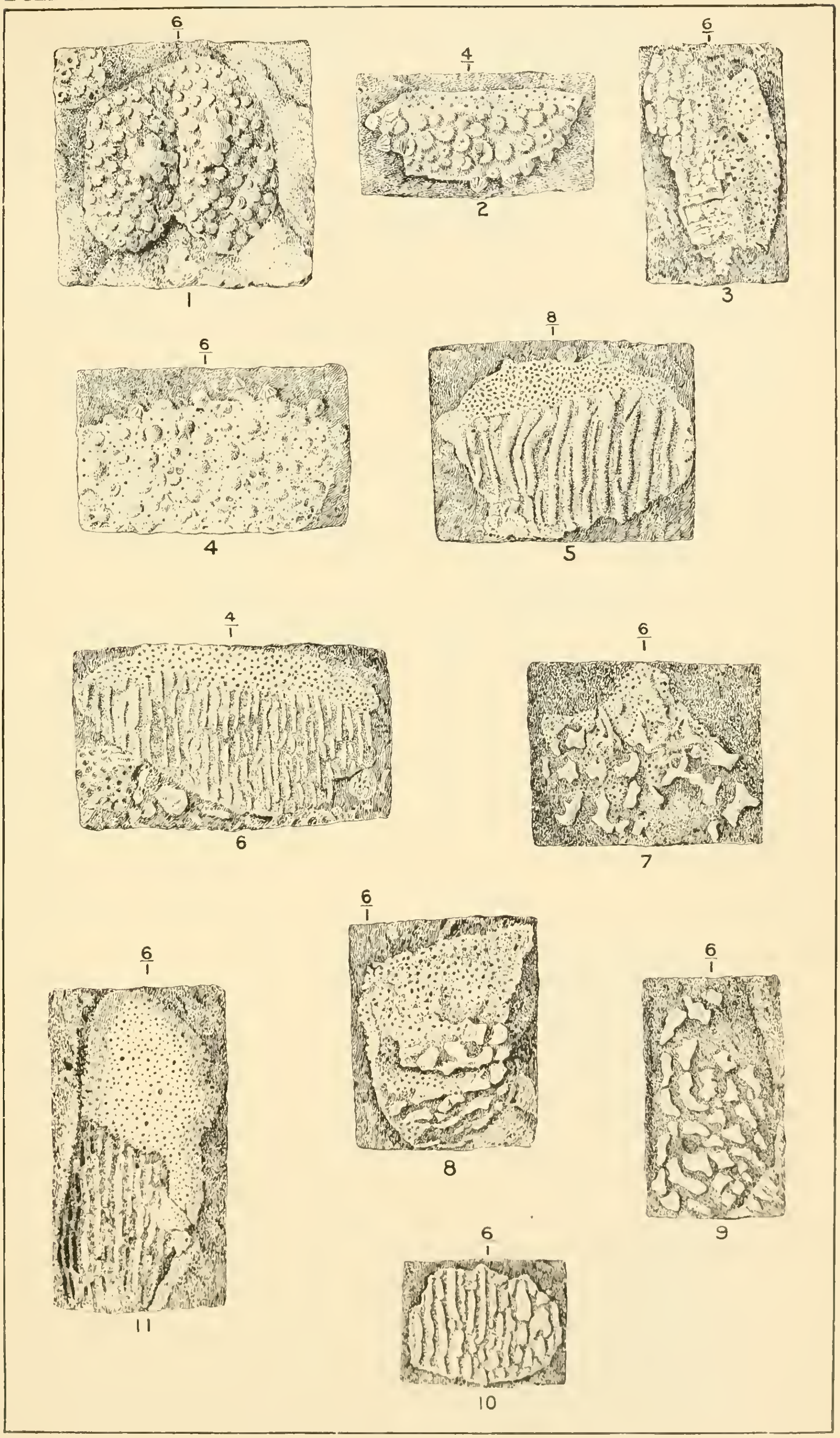
Figure 2.—Two dentine tubercles enlarged to 70 diameters.

Figure 3.—Oblique section of dentine tubercle.

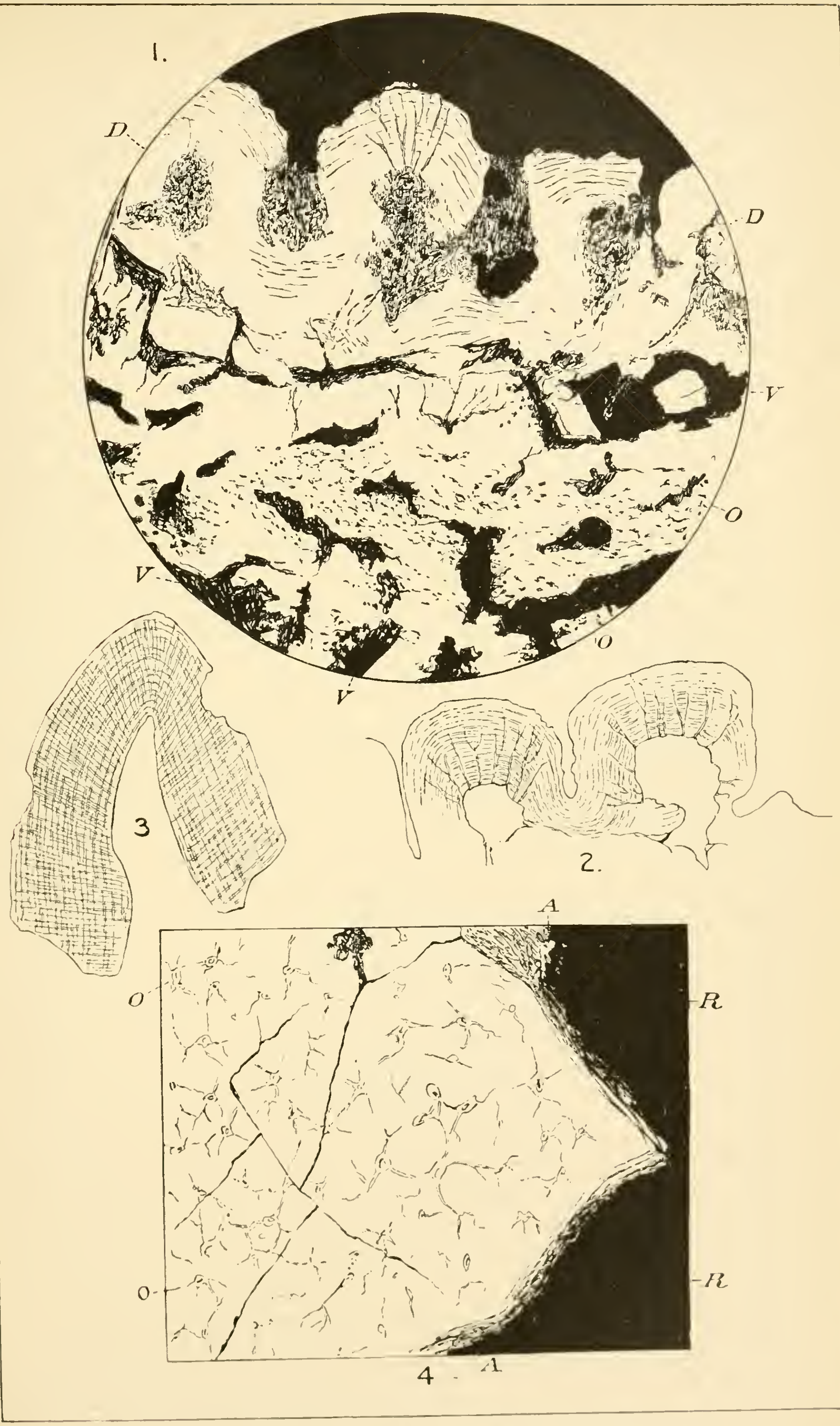
Figure 4.—Enlargement to 350 diameters to show osteoblasts (*O*). The margin is shown at *a*, *a*, and the rock at *R*, *R*.



SILURIAN ORDOVICIAN FISH REMAINS FROM COLORADO.



SILURIAN (ORDIVICIAN) FISH REMAINS FROM COLORADO.



MICROSCOPIC SECTIONS OF SILURIAN (ORDIVICIAN) FISH REMAINS FROM COLORADO.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 173-182; PP. 183-186

CERTAIN EXTRA-MORAINIC DRIFT PHENOMENA OF NEW JERSEY

ON THE NORTHWARD AND EASTWARD EXTENSION OF THE PRE-PLEISTOCENE GRAVELS OF THE MISSISSIPPI BASIN

BY

R. D. SALISBURY

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 173-182 MARCH 31, 1892

CERTAIN EXTRA-MORAINIC DRIFT PHENOMENA OF NEW JERSEY.

BY R. D. SALISBURY.

(Read before the Society August 25, 1891.)

CONTENTS.

PREVIOUS OPINIONS CONCERNING THE DRIFT MARGIN.

The terminal moraine running across New Jersey from Perth Amboy to Belvidere, and continuing thence across Pennsylvania, was first traced out under the auspices of the surveys of these states. The work in New Jersey preceded that in Pennsylvania, and was among the earliest morainic studies. In both states the terminal moraine referred to was published as representing the limit of glacial drift, and this conclusion, announced by the surveys of the respective states, was accepted by geologists as correct.

Interpreting eastern phenomena by western, glacialists not intimately familiar with the eastern field regarded the southern portion of the New Jersey and Pennsylvania drift as belonging to the first glacial epoch. The fact that the glacial drift of the interior is not limited on the south by a terminal moraine was well known, and the southern limitation of the eastern drift by a terminal moraine seemed to put the two regions in sharp contrast. But it was believed that if the known moraine of New Jersey and Pennsylvania represented the southern limit of the drift, other

moraines would be found toward the north equivalent to those of the interior, and referred to a later ice epoch. Subsequently, when glacialists familiar with the phenomena of older and younger drift sheets as developed in the interior came to study the drift of the states in question, the terminal moraines of New Jersey and Pennsylvania and the drift north of it were found to correspond in all essential points with the later glacial drift of the interior instead of with the earlier.

Still proceeding on the belief that the moraine represented the southern limit of the drift, it was inferred that the ice-advance of the later glacial times was equal to or exceeded that of the earlier, and that therefore the deposit of the latter was overridden and obliterated or obscured by the former. This interpretation, however, has never seemed entirely harmonious with the accepted interpretation of the drift phenomena of the interior. President Chamberlin has more than once expressed the opinion, though he has nowhere published it, that there might be an older drift sheet south of the moraine in New Jersey and Pennsylvania which had escaped observation. Two years since, with this suggestion in mind, though primarily for another purpose, President Chamberlin and the writer made a cursory examination of certain extra-morainic areas in New Jersey and Pennsylvania. The result of this examination was to strengthen the suspicion that glacial drift did not find its southernmost limit in New Jersey and Pennsylvania along the line of the moraine.

The phenomena which were then observed have never been published. The most significant fact developed was the existence of glacially striated stony material many miles south of the moraine at one point at least in New Jersey and at three points in Pennsylvania. The striated stones were occasionally seen to be embedded in a matrix of clayey nature, resembling till. This bowldery clay was of such a character and in such positions as to make the suggestion of its derivation from the moraine toward the north unsatisfactory if not altogether untenable. Some of the phenomena seen were capable of explanation without supposing glacier ice to have been present in the region where they occur; others seemed to us to find their most rational explanation in the supposition that glaciation had extended beyond the limit hitherto assigned it.

In June of the present year the writer visited New Jersey, and then learned for the first time that Professor Smock had long entertained the idea that there might be a formation of glacial drift south of the moraine which he had traced across the state. Professor Smock was in possession of a number of facts concerning the character of the surface formation south of the moraine which afforded sufficient basis for the idea which he entertained. When the writer undertook the detailed study of the Pleistocene formations of New Jersey a little later in the season, Professor

Smock very generously put these facts into his possession. Their nature was altogether in keeping with the facts which President Chamberlin and the writer had independently discovered two years since, and Professor Smock's inferences corresponded with our own.

Results of recent Studies.

Critical Localities and Exposures.—During the months of July and August, 1891, the localities which had raised the question of an extra-morainic glacial drift in Professor Smock's mind were visited by the writer and examined in detail, and many other localities were found where the same class of phenomena are to be seen. Some of these localities, because of their geographic positions and relations, seem to be crucial so far as the question of extra-morainic drift is concerned; and although the work on the Pleistocene formations of New Jersey is but begun, a few of the facts already developed are thought to be of sufficient importance to warrant statement before this Society.

At Oxford Furnace, at an elevation of between 500 feet and 600 feet, there is an accumulation of surface material which is certainly not of local origin. It is partly stratified and partly unstratified. It contains large bowlders of various kinds of rock, many of which show unmistakable signs of ice wear. They are so associated with clay that the unstratified portions of the material have the aspect of till. The relation of the stratified to the unstratified material is such as may often be observed in glacial drift.

This locality is not more than two miles south of the terminal moraine, and its altitude is slightly less than that of the moraine. Since this is the fact, and since the material is in part stratified, it might be inferred that the surface materials at Oxford Furnace are nothing more than derivatives from the moraine; but a critical examination of the material itself is fatal to this hypothesis. If this material were derived from the moraine by the action of water (an hypothesis which has found currency for similar formations similarly disposed elsewhere) its origin should be revealed in its structure and composition; but both its structure and composition show that it is not overwash material. Much of it is unstratified, and the relation of the stratified to the unstratified parts is most complex and not within the power of water, acting alone, to produce. Overwash gravel plains flanking the moraine are well developed in the vicinity, and their constitution and structure are well known. They consist uniformly of water-worn gravel mingled with sand. Earthy material is wanting. The unstratified material at Oxford Furnace, on the other hand, is a tough bowldery clay with its stony material abundantly striated, and

the striæ are of such a character as to make their glacial origin evident. Even among the pebbles of the stratified portions of the Oxford Furnace deposits, striated pebbles may occasionally be found, indicating that the materials have suffered but a limited transport by water. Furthermore, the relations of the stratified and unstratified materials are such as to show contemporaneity of origin.

In another sense the morainic material and the material of morainic derivation just north of Oxford Furnace are essentially unlike the Oxford Furnace deposits. The one bears every evidence of youth, and the other as strikingly bears evidence of age. In the one case the clays are unoxidized and unleached, and the stony material retains the hard fresh surfaces which characterize freshly glaciated bowlders. Even the sands, readily percolated by water, are calcareous to within three or four feet of the surface. In the other case, the clays are oxidized to great depths, the calcareous material which they presumably contained has been leached out, and a large proportion of the decomposable rock materials which the clay contains have so far yielded to the effects of weathering and solution as to have lost their integrity altogether. So striking are these differences in the two classes of deposits, good exposures of which may be seen within two miles of each other, that it cannot escape notice even in a cursory examination. If 1 represent the age of the material of the moraine, the age of the other can hardly be represented by one figure.

The higher lands southwest and west of Oxford Furnace are likewise found to be interruptedly covered by a similar drift mantle. It is generally absent from the steep slopes, is frequently present on the gentler ones, and is nearly uniformly present on the level summits. Rising from 550 feet near Oxford Furnace to 600, 700 and 800 feet, the same till-like material occurs. Near Little York, about 860 feet above tide, the same bowldery clay is exposed to a depth of ten feet or more. The stony material is predominantly small, and the larger portion of the stone is of quartzite or hard sandstone. The quartzites and hard sandstones do not commonly show glacial markings, though their surfaces are generally unweathered and sometimes show planation. The fragments of crystalline rocks (crystalline schist series) are almost uniformly so far disintegrated that they would not show surface markings even if once present.

Among the stony ingredients at this place there are many bits of soft shale. With these the case is very different. These bits of shale, soft as they are, have withstood the disintegrating action of air and water, and very many of them still preserve the surfaces they possessed at the time of their deposition. Among the fragments of shale, large and small, it

is well nigh impossible to find a piece which still preserves its original surfaces that does not show glacial striæ. Even tiny fragments but a fraction of an inch in diameter are found to be very generally marked.

When the softness of these shale fragments is considered and their association with numerous pebbles and cobbles and bowlders of hard sandstone, quartzite, etc, is borne in mind, it seems impossible to attribute their deposition to water. They are much too soft to endure even a limited amount of transportation by water without having their scorings obliterated. Much less could they stand water transportation along with hard materials, such as those with which they are associated, without having every trace of glacial striation effaced. If any added evidence is needed to prove their non-aqueous origin, that evidence is found in the shape of the fragments and in their association with materials of all grades of coarseness and fineness without trace of stratification.

The chemical and physical condition of the material near Little York is like that of the corresponding deposits near Oxford Furnace. The decomposable rocks have yielded to the influence of weathering and have lost their integrity. The clay is oxidized to the depth of the exposure and is wholly wanting in calcareous material. If this was ever present, it has been completely abstracted; in short, every feature of the material indicates age. On this ground alone it is impossible to think of it as having any genetic connection with the moraine. Furthermore, it is more than 100 feet higher than the moraine three miles or so northward. It is therefore physically impossible for it to have been derived therefrom by aqueous agencies. In the same vicinity bowlders like those of the till-like clay which has been identified up to elevations of 860 feet exist up to heights of 1,000 feet and more. In other words, the bowlders occur on the tops of the highest hills and ridges. Above 860 feet they were not seen in association with clay, but this is believed to be because of the absence of exposures. So far as surface indications afford criteria for judgment, there is every reason to believe that the bowldery clay is present on the highest lands in the vicinity, wherever they have not been subjected to a great degree of erosion.

Near Mount Bethel, a point five or six miles east of Oxford Furnace, the same type of bowldery clay, containing striated material, was seen at a height of about 960 feet. Like Oxford Furnace, this is but two or three miles from the moraine, but is several hundred feet above that part of the moraine which is nearest to it. As at Little York, the material is here wholly unstratified so far as exposed, and it occurs at the greatest elevations where exposures were found. Bowlders may be seen at the surface on the tops of the highest hills visited in the vicinity, fully 100 feet above the highest exposure of the bowldery clay seen. It is alto-

gether probable that the bowlders seen between 1,000 and 1,100 feet above tide are an index of bowlder-bearing clay existing here though not exposed.

Farther southward the same type of material occurs in the Pohatcong and Musconetcong valleys. If well data may be relied upon, there is as much as 70 feet of it in the valley near Washington, at an elevation of about 400 feet. From the localities cited it will be seen that the vertical range of the material is great within narrow geographic limits—fully 600 feet within six miles.

Still farther southward, near High Bridge, at an elevation about equal to that at Washington, or about 200 feet above the valley of the Raritan, close at hand, there is an exposure of about 30 feet of bowlder clay and gravel. As at Oxford Furnace, the material is here partially stratified, but a considerable proportion does not show any sign of orderly arrangement, and the bowlders are disposed in the clayey matrix after the fashion of true till. Bowlders five or six feet in diameter occur. One bowlder, whose greatest dimension is fully 7 feet, is glacially striated over nearly the whole of one face. As at Little York, so also here, one of the ingredients of the bowlder clay is shale in large and small fragments. Here also, as at Little York, it is difficult to find a piece of shale which retains the form it possessed when deposited which does not show ice scorings. In more than one instance bowlderets of shale were seen *in situ* showing glacial markings with great distinctness, but which were so far disintegrated as to make it impossible to remove them from their position without their crumbling to fragments. Among the fragments resulting from the disruption of shale bowlders pieces may be found which retain portions of the original surface, and upon these striæ may still be seen. The matrix in which the stony material is imbedded is locally of granite and crystalline schist origin—a sort of arkose. Its abundance may perhaps be due in part to the decomposition of the granitic material in the drift itself since its deposition.

High Bridge is about fourteen miles from the moraine at its nearest point. A few miles farther southwestward, near Pattenburg, the phenomena of High Bridge are repeated at a slightly greater elevation. But a single point of difference need be mentioned: the bowlder clay here rests on shale, the surface of which beneath the drift gives evidence of mechanical disturbance.

Similar occurrences of bowlder clay are known south of Pattenburg to a distance fully twenty miles south of the moraine. In all these places the bowldery clay is essentially constant in chemical and physical character, and whatever may be the explanation of its existence in one locality must be the explanation of it in all.

Nor are the phenomena above referred to restricted to the New Jersey side of the Delaware. South of South Bethlehem, in Pennsylvania, the same materials occur several hundred feet above the Lehigh valley. Finely glaciated bowlders imbedded in clay have been seen at more than one point south of the Lehigh at distances from the moraine comparable to those at which occur the Pattenburg and High Bridge deposits already referred to. In Pennsylvania, as in New Jersey, the material has a vertical range of several hundred feet.

Direct Evidence of Ice Work.—In the eastern part of New Jersey, near New Brunswick, some six miles from the moraine in direct line and at an elevation of 100 feet, there are some recently exposed sections which show a bowlder-bearing clay with rarely a glaciated bowlder resting on an irregular surface of Triassic shale. The irregularity is not of such a character as would be produced by erosion. It bears evidence rather of mechanical disturbance. In many places the stratification planes of the shale have been obscured by the crushing of the shale, but in other places, where the crushing effect has been less, the shale appears to have been pushed up into folds two to four feet high and with a width about equal to their height. In some cases these folds have been pushed over to one side, the bowlder clay wrapping around the inclined folds, lying beneath as well as above them. In other cases where stratification planes have been obliterated, or so nearly obliterated as to make their position indistinct, there are other phenomena exhibited scarcely less significant than those mentioned in determining the origin of the bowlder clay. There are places for considerable stretches where the material overlying the shale is essentially composed of red shale crushed to small fragments, or reduced to clay. This takes the place of the transported material which overlies the shale elsewhere. In the midst of such masses of broken shale, strictly local in origin, occasional bowlders of transported material occur, even down to the surface of the bedded shale. Exactly corresponding phenomena may be observed in many glaciated regions where the underlying rock is soft, or where a great amount of residuary material was accumulated on the surface prior to glaciation. It is quite comprehensible that such relations could be brought about by glacial action, but it is difficult to conceive how such results can be achieved by any other agency. At one other locality, fifteen miles southwest of New Brunswick, similar phenomena may be seen, though less strikingly developed.

Distribution of the Phenomena.—No determinations have yet been made as to the southern limit of this bowlder-bearing clay. The points in New Jersey and Pennsylvania mentioned above, however, are not the southernmost localities where glaciated material is known to occur. Striated bowlders have been found both by Mr. Charles E. Peet and the

writer at and near Monmouth Junction, nearly twenty miles from the moraine at its nearest point and fully forty miles south of the moraine on the same meridian. Glaciated material has also been found at Kingston, about half way between New Brunswick and Trenton. It has been found in Pennsylvania about three miles west of Trenton, near Falsingham. The similarity of the surface material of this locality to glacial drift (till) was first recognized by Professor Smock. Striated material has also been found at Bridgeport (opposite Norristown), Pennsylvania, by Mr. Peet and the writer, at least ten miles south of the parallel of Trenton. As at Falsingham, the striated material is here imbedded in clay of such a character that, were the locality known to have been covered by ice, its reference to till would be fully warranted. This locality is nearly or quite fifty miles south of the nearest point of the moraine. Striated material has also been found near Sunbury, Pennsylvania, between 25 and 30 miles south of the moraine in this longitude and at an elevation between 500 feet and 600 feet above the Susquehanna at that point. In all the localities last mentioned striation is relatively rare, but some of them have afforded bowlderets as beautifully striated as those of the Alpine glaciers of to-day.

Significance of the Observations.

General Bearing.—The foregoing statements give facts selected from a much larger body of data in the writer's possession concerning the distribution and nature and relations of extra-morainic surface formations. In the judgment of the writer these facts are sufficient to warrant the conclusion that glaciation extended further southward than the published moraine, both in New Jersey and Pennsylvania.

It is not to be understood that the writer would imply that land-ice has covered every region where glaciated material is found. The possibility of water transportation of glaciated material beyond the edge of land-ice is distinctly recognized, but it is not believed that water alone, or water bearing glacially derived bergs, could produce all the results which have been observed. Neither the physical and chemical condition of the material nor its geographic and vertical distribution are consistent with such an hypothesis.

From the character and relations of this extra-morainic drift, particularly from the degree of its oxidation, disintegration and erosion, it is confidently believed that it is to be regarded as the equivalent of the oldest glacial drift of the interior.

Number of Ice Invasions.—The conviction has been growing for some time in the mind of the writer that the commonly accepted division of

the ice period into two epochs may not be final. If this classification is to undergo modification, it is believed that the change will be in the direction of greater complexity. Data have been accumulating for some time past which would seem to be best explained on the basis of three ice epochs instead of two. This suggestion is less of an innovation than it may at first seem to be. President Chamberlin long since recognized two distinct episodes in the first glacial epoch, as classified by him, the two being separated by an interval of milder climate and ice retreat. The suggestion here made would simply emphasize this division already recognized. While President Chamberlin has hitherto regarded this interval of mild climate as marking a subordinate interruption of glaciation determining the division of the earlier ice epoch into episodes, Mr. McGee has regarded it as marking the greatest interruption of glaciation during the glacial period, determining the division of the ice period into two epochs. Mr. McGee's first glacial epoch would therefore correspond to the first glacial epoch of the classification here suggested, while his second glacial epoch would embrace the second and third as here proposed. On the other hand, President Chamberlin's first epoch embraces the first two, and his second the third epoch, if the ice period be divided into three epochs.*

Briefly characterized, the drift representing the ice advance of the first epoch has no marginal accumulation of the nature of frontal moraines. Its margin is attenuated. The drift representing the ice advance of the second epoch, according to the suggestion here made, is limited by morainal ridges, which are bordered and often covered by loess, loess-loam and silt deposits, which indicate slack drainage; while the drift of the third epoch is limited by stronger terminal moraines of more pronounced topography, in which valley trains and overwash plains of gravel take their origin. These valley trains of gravel often extend many miles down the valleys from the moraines, and demonstrate that the attitude of the land was such as to determine vigorous drainage. The degree of erosion, oxidation and disintegration of the drift of the several epochs is progressively less, from oldest to youngest. The significance of the silt and loess bordered moraines, as distinct from those bordered by gravel plains and trains in indicating continental attitudes, was long since pointed out by President Chamberlin, as was also the significance of the varying degrees of erosion, decomposition and disintegration of the drift. In briefly indicating, therefore, the broad divisions of the drift, corresponding to the three epochs suggested, the features noted are in no way

* Because of the importance attaching to his opinion on this question, I am glad to say that President Chamberlin is very hospitable to the suggestion here made of a tripartite division of the glacial period.

new, but were long since recognized by President Chamberlin and have been made use of by him and his assistants in field determinations.

Correlation of Deposits.—Apart from the inherent interest which attaches to the determination of the existence of a first glacial drift south of the moraine in New Jersey and Pennsylvania, this determination is likely to prove helpful in another direction.

The extra-morainic glacial drift in northern New Jersey and Pennsylvania affords a definite starting point for determining the relation of the glacial formations of the north to the coastal plain formations of the eastern and southeastern United States. It may not be out of place to add that the conclusion has already been tentatively reached that the "yellow gravel" formation of Dr. Cook is older than the extra-morainic drift. If this tentative conclusion shall prove to be correct, and if the drift be first glacial, then the "yellow gravel" must be preglacial, and therefore pre-Pleistocene.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 183-186 MARCH 31, 1892

ON THE NORTHWARD AND EASTWARD EXTENSION OF THE PRE-PLEISTOCENE GRAVELS OF THE MISSISSIPPI BASIN.

BY R. D. SALISBURY.

[Abstract.]

(*Presented before the Society August 25, 1891.*)

CONTENTS.

EARLY OPINION AS TO THE AGE OF THE "ORANGE SAND."

In a recent number of the American Journal of Science* President Chamberlin and myself discussed at some length the relationship of certain gravels in the middle Mississippi basin to the loess and to such other formations of that region as were demonstrably of Pleistocene age. In that article we expressed the conclusion that the gravels in question, composed mainly of chert and of other silicious impurities from limestone, were of pre-Pleistocene age. The evidence on which this conclusion was based need not here be repeated. We then believed it adequate to the conclusion reached, and nothing has subsequently been discovered by us to weaken the force of the arguments then used or to alter the conclusions based upon them.

Since the discussion referred to was published, some additional facts have come to light which have an important bearing on the question at issue. A brief note concerning these newer discoveries has already appeared in the American Journal of Science.† It is the purpose of this paper to set forth somewhat more fully the bearings of the data recently acquired.

*3d series, vol. xli, 1891, pp. 359-377.
†3d series, vol. xlii, 1891, pp. 252-253.

The attempt was long since made by the writer, under the direction of President T. C. Chamberlin, to determine the stratigraphic relationship between the glacial drift and the "Orange Sand" gravels of southern Illinois and the contiguous areas of Missouri, Arkansas, Kentucky and Tennessee. That portion of southern Illinois occupied by the southern margin of the drift is the area which has been especially studied in the hope of finding these two formations in contact, and therefore in such relationship as to determine their relative age. It was known that the "Orange Sand" gravels* extended northward to within a few miles of the glacial drift. Their distribution in the northern part of their extension was known to be much interrupted by erosion, and it was the hope that certain areas of the gravel might be found as far north as the southern limit of the drift; but up to the present season it had seemed that the southern gravels failed to reach the drift-covered territory by twenty or twenty-five miles.

Discovery of "Orange Sand" within the Drift Limits.

Ancient Gravels replacing Drift.—In May and June of the present season, what appears to be a small driftless area was found to exist in Pike and Calhoun counties, Illinois.† In this area, apparently free from northern drift, the loess was found to be underlain by an interrupted bed of gravel of variable thickness, corresponding to the "Orange Sand" gravels farther southward. The gravel is found mainly on the level uplands and on the summits of ridges where erosion has been least. It was thus determined that the gravel formation hitherto known only south of the northern drift had a northward extension much beyond the southern border of the ice-sheet; but the stratigraphic relationship of the drift and of this gravel was not directly shown by the new find, though the occurrence of the gravel in this situation—in an area completely surrounded by brift—tended strongly to confirm the previous conclusion as to its pre-Pleistocene age.

Ancient Gravels underlying Drift.—Subsequently the area surrounding the newly found driftless tract was studied, and in northern Pike, in Adams, and in Hancock counties gravel identical with that in the driftless area of Calhoun and Pike counties was found to exist. In these counties its position is such as to indicate unequivocally its relationship to the glacial drift. Wherever it is seen in section in these counties it constitutes a well defined layer inferior to the till.

* The term "Orange Sand" gravels is here used in its widest sense, including all that has been designated by this term.

† "On the probable existence of a second driftless area in the basin of the Mississippi river." Read before the Am. Assn. Adv. Sci., Section E, 1891.

South of the drift the gravel is often accompanied by considerable layers of sand. This sand may be interlaminated with the gravel, particularly in its lower parts, and often forms its substratum. In like manner in the counties referred to, far north of the southern boundary of the drift, considerable beds of sand locally accompany the gravel and sometimes remain where the gravel has been entirely removed.

Both the sand and the gravel have yielded of their substance to the till which overlies them. So generous has been their contribution that locally the drift is often largely composed of their materials. Where this is the case deep sections frequently show a remnant of the sand and gravel beneath the till in undisturbed position. From this relationship it was at once suggested that the influence of these sands and gravels in determining the character of the till over the region where they once existed might be a means of helping to determine the former northern extension of the gravels and sands. Acting upon this suggestion, the area farther north was studied, and what are believed to be unmistakable evidences of gravel corresponding to the formation of the south are found in the drift as far north as Henderson county and probably as far north as Rock Island county; but Rock Island county is not far from the southern border of the northern main driftless area.

Relations of the pre-Pleistocene Gravels.

It will be observed from what has been said that this formation of gravel regarded as pre-Pleistocene occurs south of the drift, extends northward with considerable interruptions to the border of the drift, reappears in the driftless area of Calhoun and Pike counties, passes beneath the drift north of this area, and may be recognized to the northward either in positions subjacent to the drift or by its contribution to the drift well toward the northern driftless area.

Several years since, while studying the driftless tract of southwestern Wisconsin, the writer had occasion to notice certain gravels which had been earlier described, but which manifestly had nothing to do with glacial drift. No satisfactory explanation of their origin had ever been offered. Similar gravels occur at certain localities in the driftless southeast corner of Minnesota. It is now believed to be possible and even probable that these gravels in the northern driftless area are to be correlated with those farther southward. If this be true the pre-Pleistocene (presumably Tertiary) gravels have a far greater northerly extension than has heretofore been known; and this remains true, though the extension is less great, whether the gravels of the Wisconsin driftless area are correlated with the gravels of the south or not.

Subsequent to my own first determination of the existence of these gravels above the mouth of the Illinois river it was found that Professor Worthen had already noted their existence in Hancock* and Pike† counties and had correlated them, as I think rightly, with similar gravels farther southward.‡

The extension of these pre-Pleistocene gravels northward does not appear to be their only one. To the eastward as well they have a greater extension than has heretofore been known, so far as I am aware. They have been found in Gallatin county, Illinois, near the Wabash river. This is the only point in eastern Illinois north of the Big Bay Cache valley (an old course of the Ohio) where they are known to occur. These gravels have their easternmost extension, so far as now known, near Tell City, Perry county, Indiana, where there are very considerable beds identical in all essential features with the gravels of the Mississippi valley.

In the Ohio valley, as in the Mississippi. gravel which belonged originally to the same formation has been recognized in the drift and has been seen in secondary positions many miles east of Tell City. It may, therefore, be confidently affirmed that this locality does not represent the original eastern limit of the formation, although it is many miles east of any locality north of the Ohio heretofore known to the writer to be characterized by these gravels.

---

*Geol. Survey of Ill., vol. i, 1866, p. 331.

†Geol. Survey of Ill., vol. iv, 1870, p. 37.

‡Some years previously similar gravels were described by McGee from northeastern Iowa (Geol. Mag., new series, decade ii, vol. vi, pp. 355, 360).

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 187-216, PL. 6; PP. 217-218

THE MANNINGTON OIL FIELD AND THE HISTORY OF ITS DEVELOPMENT

FOSSIL PLANTS FROM THE PERMIAN BEDS OF TEXAS

BY

I. C. WHITE

ROCHESTER
PUBLISHED BY THE SOCIETY
APRIL, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 187-216, PL. 6 APRIL 15, 1892

THE MANNINGTON OIL FIELD AND THE HISTORY OF ITS DEVELOPMENT.

BY I. C. WHITE.

(Read before the Society December 29, 1891.)

CONTENTS.

THE FIELD.

Location and general Features.—The Mannington oil field is situated in Marion county, West Virginia, on the main line of the Baltimore and Ohio railway. It is an extension of the Mount Morris (Pennsylvania) field, which begins just north of the West Virginia state line and trends in a belt of varying width southwestward across Marion and Monongalia counties to the edge of Harrison county. Dolls run, Pedlars run, Jakes run, Fairview and Mods run are centers of development along the belt, which as now defined is from half a mile to three miles wide and about 35 miles long.

The cross section on the accompanying map (plate 6) shows that the oil belt in question is found on the western slope of the Indiana anticline, and is from 15 to 20 miles distant from the great axis of Chestnut ridge. The dip is northwestward, and varies from 150 feet per mile at Mount Morris to 50 feet at Mannington. The belt is thrown westward in southern

Monongalia by the development of a new anticline which elevates the oil rock into the gas belt along its previous trend, and thus causes the oil level to veer westward, at the same time reducing the rate of dip and consequently broadening the oil belt in that region, as shown by the map.

Source of the Hydrocarbons.—The oil is found in the Pocono sandstone (Vespertine, X, etc, of Rogers) or lowest member of the Carboniferous system, its geological equivalent being the Logan sandstone of Ohio, the Shenango and Sharpsville sandstones of Pennsylvania, and the Marshall group of Michigan. This geological horizon has furnished oil at several localities in this country: the "Slippery rock" and "Manifold" oil sands of Pennsylvania, the "Mecca" sand of Ohio, and the main sand at Burning springs and Volcano, West Virginia, all belonging to the Pocono beds. It was from this same horizon that natural gas was obtained in the Kanawha valley fifty years ago, and there first utilized for manufacturing purposes. The Warfield gas wells of Kentucky are in this sand, and it also furnishes oil at many localities in that state, while the asphalt deposits (residua of evaporated petroleum) of Alabama occur in the same series. Hence it will be perceived that this horizon is one which holds hydrocarbons over a wide area, just like the older Catskill (Venango oil sands) and upper Chemung beds (Bradford and Warren sands) below.

This oil rock was several years ago dubbed the "Big Injun" sand by some facetious driller in Washington county, Pennsylvania, where it is about 250 feet thick and very hard, thus rendering the progress of the drill through it quite slow and suggesting the name which it has ever since maintained in oil parlance, viz, the "Big Injun" sand. It is also sometimes called the "Manifold" sand, from the farm in Washington county on which was obtained the only paying well in that county at this horizon, out of the hundreds and thousands that have been drilled through it, though the name "Mount Morris" sand is more appropriate, since it has proven more productive of oil in the Mount Morris-Mannington field than anywhere else.

The oil and gas are not disseminated uniformly through the sand rock but occur in "pay streaks" at 60 to 135 feet below the top of the Pocono sandstone, the richest and main horizon being found at 85 to 110 feet. At about 20 feet in the sand there is a layer which frequently furnishes a small flow of gas, but has never yet produced any oil. Then at 60 to 75 feet the "first pay" is usually obtained, and at 85 to 110 the "second pay;" while a "third pay" may be found at 120 to 135 feet. These "pay streaks" are merely coarser and more open layers of sand in which the oil, gas, or water, as the case may be, finds a good receptacle.

The texture of this sand is not coarse and pebbly like the Catskill conglomerate of the Venango sand group, and hence its oil wells are never so large as those from the latter beds, but they are on that account the

more lasting. The wells in the "Mount Morris" or "Big Injun" sand produce from 5 to 500 barrels daily, after they have been flowing for a period of thirty days, though some have been known to start off at the rate of 50 barrels an hour when first struck.

The oil is of a beautiful amber color and compares favorably with the best of that produced from "white sand" territory. Its gravity is 48° to 50° as the oil issues fresh from the wells, but this usually falls to 45° by the time it reaches the main pipe line station and starts on its journey through the great pumps of the National Transit company to tide water at Philadelphia.

THE STRATIGRAPHY.

The Mount Morris Section.—The following record of the Core well number 2, near Mount Morris, kept by Mr. John Garber, contractor, exhibits the geological relations of this oil sand to the overlying beds of the Carboniferous system in that region:

	Feet.	Feet.
Permian or Dunkard Creek series:		
Conductor (clay)	21 to 21	
Slate	104 to 125	170
Sandstone, Waynesburg	45 to 170	
Upper Coal Measures:		
Coal, Waynesburg	10 to 180	
Limestone and shales	120 to 300	
Sandstone	25 to 325	
Limestone (Great limestone)	85 to 410	355
Black slate	10 to 420	
Coal, Sewickley	10 to 430	
Limestone, Sewickley and Redstone	85 to 515	
Coal, Pittsburg	10 to 525	
Barren Measures or Elk River series:		
Slate (cased at 531 feet)	70 to 595	
Sandstone, Connellsville	55 to 650	
Red shale	35 to 685	
Sandstone	15 to 700	
Red shale	10 to 710	
Blue shale	25 to 735	
Sandstone, Morgantown (salt water at 760 to 785 feet)	55 to 790	
Blue slate	40 to 830	525
Red and blue shale (Crinoidal limestone horizon; caves badly and causes much trouble in drilling)	20 to 850	
Limestone and hard beds	80 to 930	
Red slate	5 to 935	
Sandstone, Upper Mahoning	25 to 960	
Dark slate	60 to 1020	
Sandstone, Lower Mahoning	30 to 1050	
Lower Coal Measures:		
Slate, light gray	60 to 1110	
Sandstone, Freeport	80 to 1190	
Dark slate	25 to 1215	
Limestone, Johnstown	40 to 1255	310
Dark slate	40 to 1295	
Sandstone, hard	5 to 1300	
Slate	60 to 1360	

Pottsville conglomerate:		
"Salt sand," part of XII (water at 1,442 feet)	150 to 1510	210
Slate (cased at 1,515 feet)	10 to 1520	
Limestone (?)	20 to 1540	
Slate	10 to 1550	
Dark pebbly sand	20 to 1570	
Mauch Chunk shale:		
Light-colored sandstone	95 to 1665	178
Limestone, hard	22 to 1687	
Red shale	13 to 1700	
Dark slate	45 to 1745	
Red shale	3 to 1748	
Limestone, "Mountain" or "Greenbrier"	56 to 1804	157
"Big Injun" or Mount Morris sand, with oil from 1,890 to 1,912 feet	101 to 1905	

The Mannington Section.—In the Hamilton test well (number 1) at Mannington also the record was kept by Mr. Garber, and reads as follows:

	Feet.	Feet.
Permian or Dunkard Creek series:		
Conductor (soil)	15 to 15	90
Coal, Waynesburg "A"	1 to 16	
Slate	14 to 30	
Blue sand, Waynesburg	35 to 65	
Slate (Waynesburg coal at 78 feet, but not noted)	25 to 90	
Upper Coal Measures:		
Sandstone, Browntown	30 to 120	392
Limestone	40 to 160	
Slate	35 to 195	
Limestone interstratified with thin shales	142 to 337	
Slate	8 to 345	
Coal, Sewickley	12 to 357	
Slate	35 to 392	
Limestone	48 to 440	
Dark slate	19 to 459	
Coal, Pittsburg	11 to 470	
Barren Measures or Elk River series:		
Slate	25 to 495	607
Limestone, hard	40 to 535	
Sandstone, Connellsville	35 to 570	
Slate	23 to 593	
Sandstone, hard	4 to 597	
Red shale	6 to 603	
Variegated shales	87 to 690	
Red shale	10 to 700	
Limestone (shaly), Crinoidal	45 to 745	
Coal, Crinoidal	5 to 750	
Blue slate	25 to 775	
Limestone	10 to 785	
Red shale	13 to 798	
Limestone and shales	26 to 824	
Sandstone, dark	20 to 844	
Slate, dark	31 to 875	
Sandstone, Upper Mahoning (some gas and water)	45 to 920	
Slate, gray (caving material)	65 to 985	
Sandstone, Lower Mahoning	92 to 1077	

Lower Coal Measures:			
Slate		93 to 1170	
Sandstone, hard		15 to 1185	
Sandy shales and slate		45 to 1230	
Trace of coal (Kittanning Upper coal?)			
Black slate		20 to 1250	293
Sandstone, very hard		27 to 1277	
Coal and slate, Lower Kittanning		17 to 1294	
Limestone and slate		21 to 1315	
Hard sandy shales, and slate		55 to 1370	
Pottsville conglomerate:			
White pebbly sandstone ("salt sand;" big flow of salt water at 1,385 feet)		117 to 1487	
Dark slate		31 to 1518	200
Dark pebbly sandstone		15 to 1533	
Sandy beds		37 to 1570	
Trace of coal, base of number XII			
Mauch Chunk shale:			
Light-colored slate		30 to 1600	
Red shale		78 to 1678	141
Limestone, slaty (cased at 1,680 feet)		28 to 1706	
Red slate		5 to 1711	
Limestone, "Mountain" or "Greenbrier"		92 to 1803	
"Big Injun" (Mount Morris) oil sand, composed of—			
(*a*) Gray sand (gas at 1,815 feet)	37		
(*b*) Cream-colored limestone	17	72 to 1875	219
(*c*) Dark sand	10		
(*d*) Gray sand with oil at base	8		
(*e*) Bluish gray sand (with more oil at 1,885 feet and some water at 1,910 feet)		55 to 1930	

The bottom of the Waynesburg coal should have been found in this well at about 78 feet from the surface.

The Fairview Section.—Near Fairview, 10 miles northeast of Mannington, the measures exhibit the following structure, as shown by the record of the Brice Wallace well number 1, given me by Mr. John Worthington, of the South Penn oil company:

	Feet.	Feet.
Conductor	12 to 12	
Gray slate	30 to 42	
Coal, Waynesburg "A"	4 to 46	137
Sandstone, Waynesburg	87 to 133	
Slate	4 to 137	
Upper Coal Measures:		
Coal, Waynesburg	7 to 141	
Slate	5 to 149	
White sandstone, Browntown	40 to 189	
Coal, Little Waynesburg	6 to 195	
Limestone	39 to 234	
Slate and sandy beds	50 to 284	
Limestone	36 to 320	390
Slate and limestone	60 to 380	
White sandstone, Sewickley	40 to 420	
Coal, Sewickley	10 to 430	
Slate, soft	25 to 455	
Limestone, hard	35 to 490	
Slate	30 to 520	
Coal, Pittsburg	14 to 534	

Barren Measures or Elk River series:			
Slate, white		31 to 565	556
Limestone		40 to 605	
Slate, white		15 to 620	
Red shale		25 to 645	
Light sandy beds		50 to 695	
Red and gray shales		165 to 860	
Limestone		15 to 875	
Red and gray shales		40 to 915	
Sandstone		25 to 940	
Coal (Masontown) and white slate		30 to 970	
Sandstone, hard, Upper Mahoning		35 to 1005	
Slate, dark		45 to 1050	
Sandstone, Lower Mahoning		40 to 1090	
Lower Coal Measures:			
Coal (Upper Freeport) and slate		20 to 1110	270
Dark slate and sandstone		160 to 1270	
Sandstone		30 to 1300	
Slate and sandy beds		60 to 1360	
Pottsville conglomerate:			
Sandstone (top of XII, Homewood)		50 to 1410	255
Slate and sandy beds		69 to 1479	
"Salt sand" (salt water at 1,525 feet)		136 to 1615	
Mauch Chunk shale:			
Red beds		140 to 1755	165
Slate, dark		25 to 1780	
Limestone, "Mountain" or "Greenbrier"		70 to 1850	219
"Big Injun" (Mount Morris) sand, composed of—		142 to 1992	
(*a*) Gray sand	65		
(*b*) Limestone	7		
(*c*) Sand, gray (some gas; "first pay")	20		
(*d*) Sand, gray (heavy gas; "second and third pays")	30		
(*e*) Sandstone (oil show in bottom)	13		
(*f*) Sand	7		
Slate to bottom of well		5 to 1999	

General Features.—By reference to the details of these records it will be observed that the Upper Coal Measures (XV), Barren Measures (XIV), Lower Coal Measures (XIII), Pottsville conglomerate (XII), and the Mauch Chunk shale and Mountain limestone (XI) are all well represented, and that the latter series rests immediately on top of the Mount Morris oil sand, which corresponds to formation X of Rogers, or the Pocono sandstone of Lesley.

Another interesting fact will also be observed, viz, that the interval from the Waynesburg coal to the top of the oil sand is 1,624 feet at Mount Morris, 1,706 feet at Fairview, and 1,725 feet at Mannington, thus showing a progressive increase in this interval from Mount Morris to Mannington of about 100 feet. This condition of affairs, as will be seen hereafter, plays a very important part in determining the exact course of the Mount Morris oil field when traced southwestward.

Development of the "Anticlinal Theory."

The Mannington oil field was developed by myself and associates, and as its location was made from purely scientific deductions illustrative of certain theories concerning oil and gas accumulation which I have taught for several years, a brief history of these theories and their application in the discovery of the Mannington field may not be without interest to geologists; and this must excuse much that is personal to myself in connection therewith.

As is well known, it was formerly a popular saying among practical oil men that "Geology has never filled an oil tank;" and to such a low estate had oil geology fallen that a prominent producer of oil and gas, disgusted with geology and geologists, was once heard remark that if he wanted to make sure of a dry hole he would employ a geologist to select the location. It has been my pleasant task during the last eight years to assist in removing this stigma from our profession, so that with the able and valuable assistance of Ohio's distinguished geologist, Professor Orton, Dr. Phinney, of Indiana, and others the battle against popular as well as scientific prejudice has been fought and won and this long standing reproach to geology in great part removed. The battle was opened by the publication of a paper in "Science" of June 26, 1885, entitled "The Geology of Natural Gas," by I. C. White.*

As geologists are aware, Hunt, Andrews, Minshall, Newberry, and Stevenson had all previously recognized some of the factors of oil and gas accumulation, but the paper in question contained the first clear exposition of what has been termed the "anticlinal theory" of oil and gas. As therein stated, I was led to the discovery of the laws of gas, oil and water accumulation through a remark by Mr. William A. Earseman, a practical oil operator of many years' experience, and now general superintendent of the South Penn oil company, one of the Standard oil company's most successful concerns. Mr. Earseman believed, in spite of the disrepute under which geology rested with practical oil and gas operators, that it could, if rightly applied, render them valuable service. He believed this so thoroughly that he induced Captain J. J. Vandergrift, president of the Forest oil company, to engage my services in June, 1883, for a general study and investigation of the subject, the results of which were embodied in the paper to which reference has been made. The propositions formulated then for the first time in any scientific publication provoked a discussion of the general subject of oil and gas accumulation, and as these letters and papers of mine are scattered through several journals which

* Reprinted in the Appendix, ante, pp. 201-206.

geologists generally have not read, and as they mark a new and important epoch in the history of gas and oil geology, and are therefore worthy of being preserved to geological literature in a more permanent form than they have heretofore had, I shall append to this paper a fairly complete history of that discussion so far as my own part in it was concerned, the same being compiled from the pages of *Science*, *The Petroleum Age* and the *American Manufacturer*, in which journals my contributions to this subject were originally published.

The essential principles involved in the paper and discussions referred to, as embodied in the "anticlinal theory," have been very forcibly and graphically set forth by Professor Edward Orton, whose philosophic mind and skillful hand have grappled with and raveled so many tangled threads of geologic history. Grasping at once the truth of the "anticlinal theory," he applied its principles in a striking and beautiful way to the explanation of the oil and gas deposits of Ohio. Expressed in his words, *relief* or *structure* is the essential element in the accumulation of large quantities of either oil or gas, for if the rocks lie nearly horizontal over a wide area we find, when we bore through them, "A little oil, a little gas, a little water, a little of everything, and not much of anything;" while if the rock reservoirs be tilted considerably, so that the small quantities of oil, gas, and water in all sedimentary beds can rearrange themselves within the rocks in the order of their specific gravities, then and then only can commercial quantities of each accumulate, provided the reservoir and cover are good. The anticlinal waves which traverse the great Appalachian plateau westward from the Alleghanies and practically parallel to these mountains present just such relief as the theory requires in the New York, Pennsylvania, southern Ohio, and West Virginia oil and gas fields, while the more ancient flexures in northern Ohio and Indiana account for the large accumulations of oil and gas in the Trenton limestone of those states. The Florence (Colorado) and other oil fields in the far western states and territories have this tilted rock structure, and the same relief is plain in the Canadian oil and gas fields, according to Selwyn; while Tschernyschew, Sjögren, and other geologists who have studied the foreign oil fields, report an identical geological structure there.

This theory, so simple and consonant with well known physical laws, as well as so harmonious with the facts of geology, was heartily welcomed by most of the oil and gas operators, and by nearly all geologists that have given any thought to the matter, as a satisfactory solution of the geologic problem connected with oil and gas accumulation. A few have attempted to relegate the great principle of relief to a subordinate position, but the facts have pointed so conclusively in the other direction that opposition has been silenced at least, whether convinced or otherwise.

Guided by this theory I located in 1884 the important gas and oil field near Washington, Pennsylvania; also the Grapeville gas field along that great arch of the same name in Westmoreland county; and the Belle Vernon field on the Monongahela river. On the same theory I located and mapped out, for Mr. J. M. Guffey, the celebrated Taylortown oil field of Washington county months before the drill demonstrated the truth of my conclusions. And right here on this Mannington-Mount Morris belt a derrick was built to bore for oil on one of my locations at Fairview more than five years before the drill finally proved that my location was immediately over one of the richest pools of oil in the country, and before the drill had shown that there was any oil in this portion of West Virginia. These are only a few of the positive fruits of the theory to which we can point; the negative results in condemning immense areas for both oil and gas being even more important in preventing unnecessary expenditure and waste of capital where a search for either gas or oil would have certainly been in vain.

An important corollary, drawn from the "anticlinal theory" of gas and oil, and announced as probably true in my article in *The Petroleum Age* for March, 1886, was that the pressure under which the oil and gas in any rock or field are found is of artesian origin; or in other words that the initial pressure in any oil or gas field is measured by the pressure of a column of water equal in height to that which rises from the same rock when water is struck instead of oil or gas. This was announced as the most probable theory in the paper referred to, and Professor Orton has since* demonstrated the theory to be true in Ohio with reference to the gas pressures in the Trenton limestone.

The problem of proving that the oil and gas pressures found in the various sands of Pennsylvania and West Virginia are due to artesian pressure is not so simple as in Ohio, since the one rock there emerges from the earth at the level of lake Superior, while the several sand horizons of West Virginia and Pennsylvania come up in many regions of the country from the base of the Alleghanies westward to the Ohio river and northward to lake Erie, so that one can never be certain as to the exact datum plane from which to measure the top of the water column which gives origin to pressure; and therefore while the observations prove the general truth of the theory of artesian pressure for the "white sand" rocks of Pennsylvania and West Virginia, they are not so complete and demonstrative as in Ohio and Indiana.

The gradual increase of pressure with depth is strikingly shown in the following series:

* Bull. Geol. Soc. Am., vol. 1, 1889, pp. 87–91.

	Feet below tide.	Lbs. per sq. in.
Gas in Pottsville conglomerate at Mannington	200–300	350–400
Gas in Mount Morris sand at Mount Morris and Mannington	700	500–550
Gas in Mount Morris sand at Blacksville	800	600 +
Gas in Mount Morris sand at Harrisville (West Virginia)	1,000	680 +
Gas in Gordon sand near Pittsburg	1,000	800 +
Gas in Gordon sand near Waynesburg	2,000	1,300 +

The same story is told by any other set of observations, viz, that for any particular stratum the amount of pressure its gas develops is directly proportional to its depth in about the same ratio which a column of water increases pressure with increasing length.

Since the column of salt water never rises to the surface through southwestern Pennsylvania and West Virginia, and since it is almost impossible to get the oil drillers to make accurate measurements down to the top of the water in any particular case, exact calculations as to what the theoretical pressure should be have not been made, though from close estimates by cable measurement of the height of the column of water it is known that the observed pressure in all of the "white sand" oil and gas rocks of West Virginia and southwestern Pennsylvania corresponds very closely with what it should be on the hypothesis of artesian origin. Hence these facts have precluded any other interpretation, and this origin for the gas and oil pressure has entered into all of my reasoning upon these problems.

I am aware that Professor Lesley * finds (for himself) an argument for the "expansion theory" of gas pressure in the gradual decline of the gas pressure at Murraysville and Grapeville; but he overlooks some very simple truths. During a great fire in a town supplied with water by elevated reservoirs (artesian pressure), when a dozen fire plugs are open and running under full headway, the pressure in all the street mains is greatly reduced, and yet the height of the column of water (reservoir) remains the same, and the original pressure will return when the fire is over (the water plugs being closed). Also in the distribution of illuminating gas, the pressure rapidly decreases soon after dark, when so many exits for the gas have been opened (gas jets lighted), though the pressure remains the same at the gas-holders, or has even been increased. The underground tankage of gas is an exactly paralled case to that of water or gas above ground, with the exception that freedom of movement must be infinitely greater above than below ground, on account of the capillary nature of the underground conduits; and hence *a priori* we should expect that the opening of several exits for the escape of the subterranean gases would be more marked in decreasing the pressure upon such con-

* Proc. Am. Phil. Soc., vol. xxix, 1891, p. 16.

duits. But if it were possible to close up all of these exits (gas wells) there can be little doubt that the original pressure would finally return. Of course in such a case the water would crowd into the rock and encroach upon space hitherto occupied by gas until it had compressed the remaining gas into a narrower compass and restored its original pressure.

Application of the "Anticlinal Theory."

This question of the cause of gas pressure is of more importance in connection with the geology of oil than might at first thought appear, as will be subsequently shown. It was largely upon this theory of the origin of gas pressure that I concluded that the Mount Morris oil belt would, when traced southwestward, cross the Baltimore and Ohio railway near Mannington, 25 miles in advance of any oil developments at the time the prediction was made. My working hypothesis was that since the gas pressure is due to a column of water, and since this must be practically the same for any limited area where the rock lies at the same depth below sea level, the oil deposit in this particular rock must extend across the country along the strike of the beds, in a pool comparable to the surface of a lake or a chain of small lakes, if the rock reservoir should not be equally porous everywhere along the strike. Hence, if my theory is true, it would only be necessary to follow the strike of any particular coal bed, limestone, or other stratum outcropping where the oil was actually developed in order to trace the course of the oil belt upon the surface, and thus to determine with approximate accuracy, many miles in advance of the drill, the location and width of such possible oil territory. Very fortunately for my purpose, two persistent coals, the Waynesburg and the Washington beds, cropped to the surface at Mount Morris, the first well finished there by Mr. E. M. Hukill, in October, 1886, starting immediately on top of the Waynesburg seam.

My first work was to determine the tide elevation of these coal beds, especially the Waynesburg, with reference to oil, gas and salt water as developed by the Mount Morris borings. For this purpose one of my associates, Professor T. M. Jackson, then professor of civil engineering at the West Virginia university, ran a line of levels from the Monongahela river (using a Baltimore and Ohio railway datum) out to the oil field, and made a complete survey and map of the twenty or more wells that had been drilled at that time (January, 1889) in and about the village of Mount Morris. He also obtained the elevations of the coal beds at every possible point. From the data thus acquired it was learned that wherever the Waynesburg coal has an elevation of 950 feet above tide, gas, and not oil, was found, and that where it had dipped down below 870 feet salt water was a certainty—in the Mount Morris region at least. As the

Washington coal is 155 feet above the Waynesburg bed, the gas and salt-water limits were found to be 1,105 and 1,025 feet above tide respectively, when referred to the Washington bed as a datum line.

With these facts in hand, it was only a question of correct identification, or tracing of coal beds, and a simple matter of leveling, in order to follow the strike of the surface rocks at least, for a hundred miles or more. But the query arose to me, "Suppose the surface rocks do not lie parallel to the oil sand, then where will the oil belt be found?" The interval between these coal beds and the oil sand might either thin away considerably or thicken up an equal amount in passing southward from Mount Morris. Of course, if either of these things should happen, the strike of the oil sand would not run with the strike of the surface rocks, but would gradually veer away from the latter either eastward or westward, depending upon whether the intervening measures should thicken up or thin away. To meet any such possible contingencies, the territory within which it was considered possible for oil to exist was gradually widened southward, and at Mannington extended eastward to where the Waynesburg coal had an elevation of 1,025 feet instead of 950 (the eastern limit of oil at Mount Morris), and carried westward to where it had an elevation of 800 instead of 870 feet (the western limit of oil at the north).

In following the strike line from Mount Morris to Mannington its direction was found to vary greatly. For the first five or six miles between Mount Morris and Dolls run the strike was about S. 30° W.; but toward the head of Dolls run, the line turned rapidly westward, making a great curve or elbow and running westward past the village of Fairview, from which, with many curves and sinuosities, it crossed successively Plum run, Mods run and Buffalo creek at Mannington, on a general course of S. 45° W., but varying from this 10° to 15° either way in certain localities. The strike line carried on southward from Mannington passed into Harrison county through the villages of Pleasantville and Grangeville.

This course which I thus mapped out for the extension of the Mount Morris oil belt was so crooked and passed so much farther westward than the practical oil men had considered possible that my geological line, or hypothetical belt, furnished occasion for many jokes and gibes at my expense among the oil fraternity; and it was with the greatest difficulty and only by liberal gifts of supposed oil territory that I could induce any of them to risk their money on a purely geological theory. Finally, however, a contract to drill a test well in the vicinity of Mannington was entered into in the spring of 1889 with Mr. A. J. Montgomery, of Washington, Pennsylvania, a gentleman who had given considerable thought to geology. As this was to be a crucial test of my theory, the proper loca-

tion for the test, 20 miles distant from any producing oil well, gave me no little concern, since if the well should prove a failure oil geology would receive a fatal blow, in the eyes of practical oil men, while if successful their confidence in geology would be greatly increased and strengthened.

The problem I had to solve was, whether the interval between the surface rocks and the oil sand would remain the same as at Mount Morris, or whether it would either thicken or thin: since, upon my theory, if I made a location at Mannington where the Waynesburg coal had an elevation of 900 feet above tide, and the interval from it to the oil sand remained the same (1,625 feet) as at Mount Morris, then if the oil rock proved open and porous a fair oil well should be found; while if, on the other hand, this interval should thin away to, say, 1,575 feet, then gas would be found, and if it should thicken up to 1,675 feet, salt water would be obtained, and this especially would be fatal to my theory, for the practical oil men were predicting that Mannington was several miles too far westward, and hence was in salt water territory. In the absence of any evidence bearing upon the subject, and rather in opposition to a general geological fact, viz, that the sedimentary beds thin away rapidly westward from the Alleghanies, I made up my mind to take no chances on salt water in this, the first test well, and in finally determining the location, placed it where the Waynesburg coal had an altitude of 970 feet and the Washington about 1,125 feet. Such a location at Mount Morris would have been in the gas belt by an elevation of 20 to 25 feet to spare.

As the drill progressed it was found that the intervening rocks were thickening instead of thinning when compared with the Mount Morris column, and when the top of the oil sand ("Big Injun") was finally struck, the interval from it to the Waynesburg coal measured exactly 1,725 feet instead of 1,625, as at Mount Morris. Finally, on October 11, 1889, the drill penetrated the oil-bearing zone of this sand, and was immediately followed by a copious showing of oil, the result being that my theory was at once raised from the domain of conjecture to that of demonstrated fact. Thus a great victory was won for geology, since it taught the practical oil men once for all that they could not afford to disregard geological truths in their search for oil deposits.

This thickening of the interval between the Waynesburg coal and the oil sand to the extent of 100 feet, in the distance of 25 miles from Mount Morris to Mannington, proved to have exactly the effect that I anticipated, *i. e.*, it caused the oil belt to veer eastward until (as may be seen by the accompanying map, plate 6) it gradually encroaches upon the territory occupied by the gas belt in the vicinity of Mount Morris; so that the *western* edge of the oil belt at Mannington is found where the Waynes-

burg coal has an altitude of 950 feet above tide, which is where the *eastern* edge occurs at Mount Morris, and the gas belt begins; and hence, had the first location at Mannington been made without taking into account a possible thickening, the well would have been too far westward, and a dry hole or salt water would have been the certain result. The amount of this eastward shifting of the strike of the oil sand compared with the strike of the surface rocks between Mount Morris and Mannington is something more than half a mile, and is exhibited to the eye on the accompanying map by following the 1,000 feet elevation of the Waynesburg coal between the two points. The black line representing the strike of this bed at that elevation will be seen to lie east of the oil belt at Mount Morris, but at Mannington the oil belt is found with its eastern edge just east of this 1,000 feet strike line.

Since this Mannington test well was drilled, about 200 others have been sunk along the belt, as previously defined by me, between Mount Morris and Mannington; and the correctness of my theoretical work has been demonstrated by the drill in opening up along this belt through Marion and Monongalia counties one of the largest and most valuable oil fields in the country. Fewer dry holes have been found along this belt than on any other oil belt known to me, not more than 5 per cent of the wells drilled within the defined limits proving totally dry.

It is not claimed that this same chain of reasoning can be applied with like successful results to the discovery and development of every great oil field that yet lies hidden below the surface of the Appalachian plateau, but it is believed that a correct understanding and appreciation of the principles involved and used in the discovery of the Mannington oil field cannot fail to prove most useful and helpful to both operator and geologist in limiting the expensive exploration of the drill to regions where the geological structure would indicate favorable locations for oil deposits. Of course no sedimentary bed can extend indefinitely in any direction, or even for considerable distances, without undergoing a change in the character of its constituent elements. The individual particles of which it is composed must vary in size, and the cementing material, or lack of it, must be an ever-changing quantity. For these reasons any oil rock must be quite variable in porosity, and hence its productiveness cannot be a constant amount. Where the oil sand is a mere bed of coarse gravel or pebbles like that in the famous McDonald region of Washington county, Pennsylvania, or in the great Russian oil field, then the production of an oil well seems to be limited only by the size of the bore hole; while, on the contrary, the producing rock may become so close and compact within a few feet from a large producer as to be practically barren of oil. This fact was strikingly illustrated recently at McDonald, Penn-

sylvania, since at the very time the famous Mevey well number 1 was gushing oil at the rate of 15,000 barrels daily, another well was drilled through the same "Fifth sand," only 300 feet distant, and proved to be practically dry—the character of the producing rock having undergone a great change and become so close-grained within such a short distance that it could not hold oil in paying quantity. If such changes as this can happen in the character of an oil rock reservoir within a few feet, much more would we expect such changes within a few miles; and thus it happens that although there appears to be a continuous deposit of oil in the Mount Morris sand, from the Pennsylvania line southward to Mannington, and for at least six miles beyond, yet the productiveness of the rock is not everywhere the same, because the character of the sand (reservoir) is not constant. This condition of affairs tends to concentrate the richest territory into pools of greater or less extent which are separated from each other by territory that is "spotted" or less productive.

When this tendency to change in the character of the sand or reservoir is carried so far as to render the rock impermeable to gas, oil or water for a considerable distance, then any oil belt must come to an end, and we need not expect it to set in again on the same strike of the rocks (though that is possible), but rather when the same stratum becomes again productive it will be found at a lower or higher level and on a different strike line, so that in this way we may have several parallel belts of oil in the same stratum, and occupying different levels with reference to their tidal elevation. Thus, there are numerous productive belts of the old Third Venango oil sand from Titusville, where it lies several hundred feet *above* tide, down to the southwestern corner of Pennsylvania, where it is 2,000 feet *below* tide. Hence the principles illustrated in this paper have a local as well as a general application—local, to enable the operator to follow the course of the oil belt when discovered; and general, to enable him to limit his search for oil territory to the localities where the geological structure is favorable.

An effort has been made to find oil on the Mount Morris-Mannington belt in Harrison, Doddridge and Gilmer counties southwest of Marion; but the oil rock has changed its character completely along the strike of this belt, becoming slaty and changing to limestone; so that although some oil and gas have been found in this stratum in both Doddridge and Gilmer counties, 50 miles from Mannington, the rock is too close-grained to hold oil in merchantable quantity. Nevertheless, its presence in small quantity at the right geological and tidal elevation at distances along the strike so far away from Mannington as Big Isaac in Doddridge county and Tannersville in Gilmer demonstrates the correctness of the structural theory.

Just where the Mannington belt will end toward the southwest is, as yet, uncertain. Oil has been developed along it to within one mile of the Harrison county line, but in my opinion the belt will end not far from the latter point, since at the farthest well in advance (Blaker number 1) the sand is becoming limy and much split up with slate.

It is quite probable that in passing westward from this non-productive region down the dip of the rocks through Harrison, Gilmer and Doddridge counties the sand may improve in quality, and another belt on a different strike may be found, since there is a dip of about 300 to 400 feet before we come down to the bottom of the geological slope and reach the floor of the Appalachian basin.*

The lower group, or Venango oil sand, has not yet produced oil in any of the half dozen wells drilled through these sands along the Mount Morris-Mannington belt, but some gas has been found in Marion and Harrison counties and quite a large flow in Doddridge county; so that there can hardly be any doubt that when the proper search is made in these sands further down the slope of the rocks than in the few trial borings already made, oil will be developed in large quantity, just as certainly as the drill shall find a good, porous sand reservoir in this series of deposits, since the group of beds making up the Venango series is still present in Monongalia, Marion, Harrison and Doddridge counties, at least, and of about the same thickness and structure as in Washington and Greene counties, Pennsylvania.

The Origin of Petroleum.

The geological structure in the Mount Morris-Mannington field is so plainly connected with the accumulation of the oil deposits that considerable light is thrown upon the much mooted problem as to the genesis of petroleum.

The gas is on one side of a long slope of sand, with salt water on the other and the oil between. Did the petroleum in this Mount Morris sand come up from below and simply stop in the sand as a reservoir because it could not escape to the surface, or did it originate in the sand rock itself? The rock is an ancient sea-beach or shallow water deposit, and where exposed at many localities in the country contains marine shells, fucoids, and frequently land plants in such quantity as to form thin coal seams, which have even been found by the drill in regions where this rock is barren of oil; so that there was evidently no lack of organic matter in the original deposition of the rock. When the drill descends below this stratum a succession of gray and red shales, with other sand rocks, occurs

*Since the reading of this paper a promising oil well has been drilled at Center Point, Doddridge county, several miles west of the Mannington strike line.

in the next 1,000 feet, there being but little bituminous slate in that interval, and probably none for an interval of 3,000 feet more, or until the horizon of the Marcellus slate of the Hamilton series is reached.

Does it appear probable that this petroleum has ascended through nearly a mile of close-grained slates and sandstones, and simply stopped on its upward course at the horizon in which we find it? I think not; but rather that the organic matter deposited with and in the sandstone has been converted into petroleum and gas within the rock itself, and that the tilting of the beds has permitted the small quantities of water, oil and gas in all the porous portions of the rock to rearrange themselves in the order of their several specific gravities under the artesian pressure to which the rock is subjected, so that merchantable quantities of each have been accumulated. This seems to be the more probable origin of the Mount Morris-Mannington oil pool, at least, though of course the particles of oil, gas and water would rearrange themselves in the manner found however they might have come into their present reservoirs.

APPENDIX.

THE "ANTICLINAL THEORY" OF NATURAL GAS.*

BY I. C. WHITE, OF THE U. S. GEOLOGICAL SURVEY.

At the request of the editor of this paper the writer has consented to arrange an article for publication on the above subject. As many of the readers will perceive, it consists principally of what has already been published by me in other journals, but here brought together and condensed into one paper for the convenience of those interested in the subject.

The "anticlinal theory" of gas is not entirely new, since both Dr. Newberry and Dr. Stevenson long ago recognized *disturbance in the rocks* as a factor in the occurrence of oil (and consequently of gas).

Also, Mr. F. W. Minshall, an oil operator of many years' experience, had, it seems (from a recent letter in *The Petroleum Age*), several years since, recognized the connection between anticlinal structures and large deposits of natural gas, and it is quite probable that the same conclusion has been formulated in the minds of many other oil operators from the results of their practical experience in drilling; but so far as the writer knows, Mr. William A. Earseman was the first person who proposed to test the theory practically by locating trial borings for gas on the crests of anticlinal folds.

The subject was first brought prominently to the attention of geologists and others interested in natural gas by a short paper from the writer published in *Science* of June 26, 1885, and as the statements therein contained embrace the "anticlinal theory" as held by its friends and promulgators, it is here republished in full, in order that its claims may not be misrepresented. The paper in question read as follows:

"The recent introduction of natural gas into general use as a source of heat for industrial and domestic purposes has raised it from the rank of a mere curiosity to one of the earth's most valuable treasures.

"To the reader unacquainted with the great change natural gas has effected in all industries where it can be obtained, the following quotation from an article in *Macmillan's Magazine* for January, written by Mr. Andrew Carnegie, the chief iron master of Pittsburg, will be a revelation: 'In the manufacture of glass, of which there is an immense quantity made in Pittsburg, I am informed that gas is worth much more than the cost of coal and its handling, because it improves the quality of the product. One firm in Pittsburg is already making plate glass of the largest sizes, equal to the best imported French glass, and is enabled to do so by this fuel. In the manufacture of iron, and especially in that of steel, the quality is also improved by the pure new fuel. In our steel rail mills we have not used a pound of coal for more than a year, nor in our iron mills for nearly the same period. The change is a startling one. Where we formerly had 90 firemen at work in one boiler-house, and were using 400 tons of coal per day, a visitor now

* Reprinted from the "Natural Gas Supplement" to the *American Manufacturer* for April, 1886, pp. 11–13.

walks along the long row of boilers and sees but one man in attendance. The house being whitewashed, not a sign of the dirty fuel of former days is to be seen; nor do the stacks emit smoke. In the Union iron mills our puddlers have whitewashed the coal-bunkers belonging to their furnaces. Most of the principal iron and glass establishments in the city are today either using this gas as fuel or making preparations to do so. The cost of coal is not only saved, but the great cost of firing and handling it; while the repairs to boilers and grate-bars are much less.'

"This new fuel, which bids fair to replace coal almost entirely in many of our chief industrial centers, has not received that attention from the geologist which its importance demands. So far as the writer is aware, nothing has been published on the subject which would prove of any value to those engaged in prospecting for natural gas, and it is the existence of this blank in geological literature that has suggested the present article.

"Practically all the large gas wells struck before 1882 were accidentally discovered in boring for oil; but when the great value of natural gas as fuel became generally recognized, an eager search began for it at Pittsburg, Wheeling and many other manufacturing centers.

"The first explorers assumed that gas could be obtained at one point as well as at another, provided the earth be penetrated to a depth sufficiently great; and it has required the expenditure of several hundred thousand dollars in useless drilling to convince capitalists of this fallacy, which even yet obtains general credence among those not interested in successful gas companies.

"The writer's study of this subject began in June, 1883, when he was employed by Pittsburg parties to make a general investigation of the natural gas question with the special object of determining whether or not it was possible to predict the presence or absence of gas from geological structure. In the prosecution of this work I was aided by a suggestion from Mr. William A. Earseman, of Allegheny, Pennsylvania, an oil operator of many years' experience, who had noticed that the principal gas wells then known in western Pennsylvania were situated close to where anticlinal axes were drawn on the geological maps. From this he inferred there must be some connection between the gas wells and the anticlines. After visiting all the great gas wells that had been struck in western Pennsylvania and West Virginia, and carefully examining the geological surroundings of each, I found that every one of them was situated either directly on or near the crown of an anticlinal axis, while wells that had been bored in the synclines on either side furnished little or no gas, but in many cases large quantities of salt water. Further observation showed that the gas wells were confined to a narrow belt, only one-fourth to one mile wide, along the crests of the anticlinal folds. These facts seemed to connect gas territory unmistakably with the disturbance in the rocks caused by their upheaval into arches, but the crucial test was yet to be made in the actual location of good gas territory on this theory. During the last two years I have submitted it to all manner of tests, both in locating and condemning gas territory, and the general result has been to confirm the anticlinal theory beyond a reasonable doubt.

"But while we can state with confidence that all *great gas wells* are found on the anticlinal axes, the converse of this is not true, viz, that *great gas wells* may be found on *all anticlinals*. In a theory of this kind, the *limitations* become quite as important as or even more so than the theory itself; and hence I have given considerable thought to this side of the question, having formulated them into three

or four general rules (which include practically all the limitations known to me, up to the present time, that should be placed on the statement that large gas wells may be obtained on anticlinal folds), viz:

(*a*) "The arch in the rocks must be one of considerable magnitude.

(*b*) "A coarse or porous sandstone of considerable thickness, or, if a fine-grained rock, one that would have extensive fissures, and thus in either case rendered capable of acting as a reservoir for the gas, must underlie the surface at a depth of several hundred feet (500 to 2,500).

(*c*) "Probably very few or none of the grand arches along mountain ranges will be found holding gas in large quantity, since in such cases the disturbance of the stratification has been so profound that all the natural gas generated in the past would long ago have escaped into the air through fissures that traverse all the beds.

(*d*) "Another limitation might possibly be added, which would confine the areas where great gas flows may be obtained to those underlain by a considerable thickness of bituminous shale.

(*e*) "Very fair gas wells may also be obtained for a considerable distance down the slopes from the crests of the anticlinals, provided the dip be sufficiently rapid, and especially if it be irregular or interrupted with slight crumples. And even in regions where there are no well marked anticlinals, if the dip be somewhat rapid and irregular, rather large gas wells may occasionally be found, if all other conditions are favorable.

"The reason why natural gas should collect under the arches of the rocks is sufficiently plain, from a consideration of its volatile nature. Then, too, the extensive fissuring of the rock, which appears necessary to form a capacious reservoir for a large gas well, would take place most readily along the anticlinals where the tension in bending would be greatest.

"The geological horizon that furnishes the best gas reservoir in western Pennsylvania seems to be identical with the first Venango oil sand, and hence is one of the Catskill conglomerates. This is the gas rock at Murraysville, Tarentum, Washington, Wellsburg, and many other points. Some large gas wells have been obtained in the Subcarboniferous sandstone (Pocono), however, and others down in the third Venango oil sand (Chemung).

"In Ohio, gas flows of considerable size have been obtained deep down in the Cincinnati limestone, while in West Virginia they have been found in the Pottsville conglomerate: hence natural gas, like oil, has a wide range through the geological column, though it is a significant fact that it is most abundant above the black slates of the Devonian."

The conclusions announced in the foregoing article were criticised by Mr. Charles A. Ashburner, geologist in charge of the geological survey of Pennsylvania, who claimed, in effect, that the relation between gas wells and anticlinals was one of coincidence merely, or of the same nature as Angell's "belt theory" of oil, and also that large gas wells could be found in synclines.

To this criticism the writer published the following reply in *Science*, of July 17, 1885:

"In reply to Mr. Ashburner's criticism of the views advanced in my article on natural gas, I would say that the necessary brevity of the paper in question prevented the mention of many facts that might have rendered the conclusions clearer and less open to challenge. One of these is that my communication had especial reference to the natural gas regions proper, *i. e.*, where the gas is unconnected with

oil fields. Most geologists know that natural gas in large quantities exists with and contiguous to every oil pool, apparently as a by-product in the generation of the oil, and of course the rocks are filled with it wherever it can find a reservoir. To gas wells from such sources Mr. Ashburner's criticism may sometimes be found applicable; but, even with these, by far the larger ones will be found on the arches of the rocks.

"The cases that Mr. Ashburner mentions, where large gas wells have been found at the centers of synclines, do not necessarily contradict my conclusions; for no one knows better than he that a subordinate crumple or anticlinal roll often runs along the central line of a syncline.

"My excuse for writing the article on natural gas was that I might be of some service in preventing the waste of capital that has been going on within a radius of fifty miles from Pittsburg by an indiscriminate search for natural gas; and it is a sufficient answer to Mr. Ashburner's criticism to point him to the brilliant lights along the crests of the Waynesburg, Pinhook, Washington, Bull creek, Bradys bend, Hickory, Wellsburg, Raccoon, and other anticlinals, and also to the darkness that envelops the intervening synclines, in which hundreds of thousands of dollars have been invested without developing a single profitable gas well. The same result has been proven in other portions of the country. The Great Kanawha valley above Charleston has been honeycombed with borings for salt, and the only gas wells developed were found within a belt a few rods wide, which coincides with the crest of the Browntown anticlinal, where immense flows were struck. In this connection I should state that Colonel Allen, of Charleston, says he can trace the Browntown anticlinal by the escaping gas across streams, and even mountains, from the Kanawha river to the Big Sandy, where, on its crest, near Warfield, two of the largest gas wells ever known have recently been struck. At Burning springs, on the Little Kanawha, the only large gas wells were found on the very crest of the great uplift in that region. The gas belt of western Ohio, through Findlay and other towns, follows closely the line of the Cincinnati arch, and the same story is repeated in other localities too numerous to mention.

"Mr. Ashburner can, if he chooses, interpret these facts as mere coincidences, and explain them to himself as having no more bearing on the question of finding gas than "Angell's belt theory" of oil; but the practical gas operator can no longer be deluded by such logic into risking his money in water-holes (synclines) where so many thousands have been hopelessly squandered.

"With regard to the anticlinal theory not being 'a practical basis for successful operations,' I deem it a sufficient reply to state that all the successful gas companies of western Pennsylvania and West Virginia are getting their gas from the crests of anticlinal axes, while those that have confined their operations to synclines have met with uniform financial disaster.

"The statement was distinctly made in my original communication that gas would not be found on all anticlinals, nor at all localities along one that actually produces gas, since other factors have to be considered, as there stated; but, with the facts before us, it would certainly prove a great saving of capital in the search for gas if operations were confined to the crests of the anticlinals, and I fail to perceive how Mr. Ashburner's fears for the 'misleading' character of my article can be realized."

Mr. Ashburner replied to this in *Science* of September 4, 1885, and has written further on the subject in a paper read before the American Institute of Mining

Engineers, Halifax meeting, 1885, and also in *The Petroleum Age* for January, 1886. As a general reply to these strictures and also to illustrate the theory more fully, the writer prepared a paper for *The Petroleum Age* which was published in the March number of that journal, along with a map of western Pennsylvania, on which were located the principal anticlinal lines, and also the large gas wells. Since the article in question contains several points of interest not hitherto given to the public, the principal portion of it is here republished, without the map, which can be procured from *The Petroleum Age* by any reader who wishes it for reference :

"Where the anticlinal lines are drawn full on that map they represent actual observations of myself or others, but the dotted lines are projections of arches observed only at a few points; for instance, Mr. Ashburner states that the Sheffield gas wells are on the crest of an anticline, and when the Martinsburg axis of Mr. Chance is projected approximately parallel to the others it passes through the Sheffield region; hence the two are assumed to be identical, and the same principle has been followed in making the other projections.

"There are probably other flexures in the rocks which traverse the district in question that, in the rapid survey made of some of the counties, were not detected by the assistant geologists of the Pennsylvania survey. The writer pleads guilty to some mistakes of this nature, as well as of getting one anticlinal confused with another, in the case of the Fredericktown uplift. This mistake, which was corrected by Mr. H. Martyn Chance, in report V, may possibly have been duplicated by others of the assistants before they became expert at detecting minute changes in dip or stratification.

"An inspection of the accompanying map will reveal the fact that the main northeast and southwest anticlinals are cut by another set at nearly right angles, which have been termed cross-cut anticlinals. To Mr. Ashburner belongs the credit of first calling the attention of geologists to this feature in the rock structure of Pennsylvania, and the great Kinzua-Emporium cross-cut wave which he first traced through Cameron, Elk and McKean counties is shown on the present map.

"The surveys of the western counties of Pennsylvania were practically finished before the publication of Mr. Ashburner's observations in the northern portion of the state, and hence although similar phenomena were observed they were not described in similar terms or referred to similar causes. Thus, Stevenson (as well as Rogers long ago) recognized a great bulge in the Chestnut ridge uplift, near Uniontown, by which the Hamilton rocks are elevated to the summit of the mountain, but the arch dying down both north and south, the Catskill rocks fail to reach the surface where the axis crosses the gorge of Cheat river in the one direction, and the Chemung beds are completely buried at the Conemaugh gap in the other.

"During the last two years the writer has given considerable thought to these cross-cut axes, and the results show that a cross-cut anticlinal (presumably identical with the one crossing Chestnut ridge near Uniontown) goes through the famous Cannonsburg and Hickory gas regions in Washington county, while another parallel to it, and a few miles west, goes through the village of Pinhook, or Lone Pine, and also cuts the McGuigan gas field.

"Another of marked extent has recently been traced by the writer through the Murraysville and Grapeville region of Westmoreland county, the greatest gas field in the world, so far as present developments show. Groups of wells also appear to cluster along the grand arch that Mr. Ashburner has traced through northern Pennsylvania.

"Having observed the importance of these cross-cut arches in the location of gas

territory, I wrote Mr. Ashburner, suggesting that there might be some disturbance of the rocks in the region of Kane, where he claimed large gas wells were found in an undisturbed syncline.

"The recent discovery of oil in the Kane region has led to the drilling of many wells, and in the Oil City *Derrick* of a recent date the statement is made on the authority of Mr. McKinney, of the Union oil company, that a rapid northward dip had been found, *i. e.*, a subordinate cross-cut anticline parallel to the main one north of Kane passes through the Roy and Archer gas region. Whether this shall turn out true or otherwise, there is certainly no inherent improbability against finding such subordinate waves.

"Very unexpected and surprising was the testimony on this head which came to me recently from Mr. L. R. Curtiss, of Mendota, Illinois, who, unknown to myself, made a careful study of the geological conditions under which natural gas occurs in that state, and reached the same conclusions quite independently of my own views, as will be seen from the following paragraphs, quoted by permission from his letter to me on the subject:

"'The principal anticlinal axis of Illinois puts out in Ogle county, in the northern part of the state, and extends in a direction S. 20° E. through La Salle and Champaign, and thence to Coles and Clark counties, in the southeastern part of the state. Along this axis natural gas can be traced in springs and well borings for a distance of 160 miles. *It is, however, more prevalent on the crowns of the cross-axes.* This is notably the case at Mendota, where the cross-axis intersects the main anticline at an angle of 85° (running S. 65° W.), and on the summit of this fold the gas belt extends southwestward into Bureau county for over twenty-five miles. The other cross-axes located further to the south intersect two or three low anticlinals toward the Mississippi, and trend in the direction of the gas fields in McLean, De Witt, Macon, and Montgomery counties.'

"This same story is repeated in Ohio, according to the testimony of the eminent state geologist, Professor Orton (see his letter in Ohio *State Journal* of recent date).

"Now what is the effect of these cross-cut axes on geological structure? Evidently one effect would be to cause the arches and corresponding troughs themselves to rise or sink, as we approach or recede from the cross-cut as the case may be; for example, the general rule is that the rocks of western Pennsylvania dip down to the southwest along the line of the anticlinals, as well as away from them (N. W. and S. E.), but in the region of Cannonsburg this rule is reversed and the rocks *rise* rapidly (seventy-five feet per mile) to the southwest along both anticlinals and synclinals until the crest of the Hickory-Houstonville cross-cut arch is passed, when a rapid *dip* begins in the same direction (southwestward), thus forming at the points of intersection a kind of "hog-back" structure (as Mr. Earseman terms it) from which the rocks dip away in every direction.

"Hence these cross-cut arches result in carrying the anticlinal structure and a line of disturbance in the rocks directly across the trend of a syncline, and a failure to grasp this fact is the principal reason why Mr. Ashburner insists upon his readers believing that a great gas well may be obtained in a syncline; for it is quite certain that no large gas well has ever yet been found in the trend of a syncline, except where the trough itself has been elevated by a long rise from the southwest, which is, of course, brought about by the cross-cut folds.

"These are the geological surroundings of all those wells which Mr. Ashburner cites from northern Pennsylvania and southern New York as occurring in synclines. It is not necessary to show a reversed or northeast dip in order to

demonstrate the existence of one of those cross-cut waves, since their crests are (like some of the main northeast and southwest anticlinals) often marked by a simple flattening of the rate of dip along the latter. Professor Orton would call such a structure (where there is no reversal of dip, but only a change in rate) a *suppressed anticlinal*, a very good name, for such it really is.

"It follows, of course, that as a synclinal structure may be converted into an anticlinal one by the presence of the cross-cut wave, so the reverse may and frequently does happen, of which we have a notable instance in the region immediately adjoining Pittsburg. Here the anticlinals all sink down toward the southwest until we reach the bottom of a cross-cut trough, where they begin to rise again toward Cannonsburg, the result of which is to flood all the porous rocks under Pittsburg with salt water. The numerous wells drilled at Pittsburg show a good reservoir (Mr. Ashburner's prime factor for gas wells); but geological structure dominates here as everywhere else, and fills the reservoir with water, so that the little gas obtainable is practically useless, though when structure has elevated this reservoir out of the water at Tarentum on the north and Cannonsburg on the south, gas is obtained in abundance.

"Another cross-cut anticlinal passes along the Conemaugh river, intersecting Leechburg and Butler, its path being marked by a line of gas wells across synclinals as well as anticlinals.

"Having now glanced at some of the general structural features under which large gas wells are found, we shall consider a few of the individual arches and troughs in order to illustrate some of the general principles to which reference has been made.

"*Laurel Hill and Chestnut Ridge Anticlinals.*—The arches made by these great axes would, in my opinion, come under the ban of exception (*c*), and hence the rocks would probably be fissured too much to retain large quantities of gas. This is only an inference from theory, however, since so far as I am aware only one or two wells have been bored near the crown of either arch. One of these was bored for oil in Monongalia county, West Virginia, where the Chestnut ridge axis crosses Decker's creek, six miles southeast of Morgantown. This well began at the base of the no. XI limestone and descended about 400 feet, and hence did not penetrate the great Murraysville gas horizon (first Venango oil sand). Whether or not these large arches may furnish gas when they have flattened out to much lower waves in northern Indiana and Cambria counties is a question that only the drill can settle, though the fact that some gas was obtained at Cherry Tree, near the Nolo anticlinal (between Laurel hill and Chestnut ridge), would seem to render the hope not entirely groundless. In fact it is within the range of possibility (though not probable) that if a hole were sunk to a great depth on these arches, where they exhibit even a large development, gas might be found. The drill has this question to settle yet, since the two deep wells drilled in the synclines at Johnstown and Wellersburg could not be expected to find gas. Those drilled in the Ligonier valley were also in a syncline, and hence obtained only small quantities of gas.

"Coming still further westward we find that several wells have been bored along the western slope of Chestnut Ridge, about half way down the dip from the crown of the arch. One of these on Deckers creek and two on Cheat river, West Virginia, found a considerable quantity of gas in no. XII (the first great gas horizon), but the rock, as might have been expected, was filled also with water, which rendered the gas useless. The wells bored under nearly the same conditions as to locations in Westmoreland county found very little gas.

"The next arch westward from Chestnut ridge is the Indiana axis of Platt. This is a very sharp and well defined wave in Westmoreland county, the vertical distance from the crest to the bottom of the troughs on either side being in some places not less than 800 feet or even more; hence, unless its proximity to the great arch of Chestnut ridge should affect it, we would on the 'anticlinal theory' naturally expect it to furnish good gas wells, provided the proper kind of reservoir exists under the surface. Messrs. Guffey and Mellon have recently finished a well on this arch near Latrobe, which yields from five to six hundred thousand feet of gas daily. Some drilling was once done in the vicinity of Blairsville, where the arch crosses the Conemaugh river, but no large flow of gas was obtained, probably because the well was situated too far from the crest of the arch.

"Going still further northeastward we find the well which supplies the town of Punxsutawney with gas is situated close to this fold.

"The next arch is the great Saltsburg axis of Stevenson, the descent on each side of which is quite as great as that of the Indiana arch. This is far enough away from the Chestnut ridge disturbance to remain unaffected by the latter, and hence ought to furnish a fair test of the 'anticlinal theory.' The writer recently located a well on this arch for J. M. Guffey & Co., just north from the town of Grapeville, and when the Murraysville sand was reached a few weeks ago an immense flow of dry gas was struck.*

"Some gentlemen from Greensburg, however, who, like Mr. Ashburner, seemed to think gas could be obtained in a syncline, drilled a well one mile east from the crest of the arch, at a locality where the dip had carried the rocks down 250 feet below the crest of the Saltsburg wave. The result was that although a splendid reservoir of great thickness was found, it contained an immense supply of water. and consequently what little gas was obtained was worthless. These wells, the one furnishing a large *gas* flow and the other a large *water* flow, are only two and one-half miles apart, the former on the crown of the arch, the latter nearly a mile east from the same. No fairer test than this could be asked for the merits of the 'anticlinal theory.'

"The next arch westward is the *Waynesburg axis*, and the only gas wells obtained along the Monongahela river, among the many that have been bored, are found on its crest at Bellevernon, though the fold being low and flat, no large wells have been struck.

"The great Murraysville arch was regarded by Professor Stevenson as identical with the Waynesburg fold, the latter having been shifted eastward; but, however, this may be, there is no doubt about the one dying away to the north and the other to the south, and hence I have termed the western fold simply the Murraysville axis. This, like many other well known arches in Pennsylvania, is a double fold, with the crests about one-half mile apart, though the depression between them is very slight. As every one knows, the forty or more great gassers in that region are clustered along the Murraysville anticlinal, water being obtained in the synclinal at Irwin on the east and at Walls on the west. 'But,' says the opponent of the 'anticlinal theory,' 'you get water with the gas even along the Murraysville

*"Since this was written two other wells have been drilled to the Murraysville sand, on the crown of the Saltsburg arch, near Grapeville, and competent judges, who have seen all the great gas wells in the country, pronounce them much the largest that have ever yet been struck; so that my prediction of three years ago, that the Grapeville region would furnish larger wells than the Murraysville, has been literally fulfilled. This conclusion was based on *geological structure* alone, since the Grapeville, or Saltsburg arch, is a much grander one than the Murraysville fold. Can Mr. Ashburner explain this away as a case of coincidence of the Angell "belt theory" kind?

arch when you come south of the Pennsylvania railroad; hence of what account is the theory, anyhow?' 'My critical friend,' we answer, 'you have not observed wisely, else you would have seen that the Murraysville arch dies down and flattens out very rapidly into the great cross-cut syncline trough which embraces the city of Pittsburg, and a broad belt on either side, and the 'anticlinal theory' of gas teaches that it is quite as unwise to expect large gas wells on an arch so situated structurally as in a genuine syncline: for whenever the dip along the axial line begins to equal or surpass the total height of the wave, water may be confidently expected.' Hence, although some very large flows of gas have been struck near where the Murraysville arch crosses the Youghiogheny river, yet the quantity of water in the rock was so great that the gas was soon drowned out. The same principle accounts for the water in the Venice well of Washington county, which is located near the structural line of the Bradys bend axis, and so of others that have been pointed to as contradicting the 'anticlinal theory.' And thus we might go over the entire list of anticlinals; but as the story would be practically the same everywhere, it is useless to tire the reader's patience with details. It has been shown that the great gas wells cluster along the anticlinals, and where any marked exception to this rule occurs we find a cross-cut arch is the disturbing cause, and hence the seeming conflict is the strongest confirmation of the real essence of the 'anticlinal theory,' which, condensed and simplified into the fewest words, means that *structure* is the main factor in a search for great gas wells; that *disturbance* in the rocks by which they have been elevated above the same beds in contiguous regions, either on the crest of an anticlinal arch or along the axial lines of the synclines themselves (where cut by the cross-arches) is an essential element in finding large and lasting wells, free from water, and therefore entitled to be called 'great.'

"It is true that a considerable quantity of gas may be so shut in by close rock (through which it cannot pass) as to be imprisoned even in a syncline, and when first struck may deliver a large quantity of gas, and the same may be true where the rocks are nearly horizontal, especially in regions contiguous to oil territory; but such wells soon blow themselves out and cease to deliver gas, like the famous 'Mullen Snorter' and 'Kane Geyser,' which figure so largely in Mr. Ashburner's criticism of the 'anticlinal theory.'

"Reference has also been made to the gas wells at Erie and Fredonia as evidence against the 'anticlinal theory,' since it is claimed there are no anticlinal waves near these localities. To any one who deems these wells evidences against what I have claimed for the 'anticlinal theory,' I must request him to read more carefully the quotations from my original paper found in this article, where he will not find the statement that *all* gas wells occur on anticlinals, but instead, all *great* gas wells are found close to anticlinal arches. Now what is a 'great well?' It is probable that no gas well yet struck ever delivered more than thirty to thirty-five million cubic feet of gas daily. Some have been measured in the Murraysville field that, if we can believe the figures, have yielded thirty-three million feet daily. This is one extreme; but certainly by no stretch of language could the term 'great' be applied to wells like those of Erie, Fredonia and elsewhere along lake Erie which, according to Professor Orton's measurements, yield only from twenty to sixty thousand feet daily.

"Moreover, so far as Erie is concerned, a recent and careful study of the stratification there has revealed to the writer the presence of low waves in the same, approximately parallel to the lake, which were undetected in the necessarily hasty examination made several years ago for the Pennsylvania geological survey.

"As every one knows, it is scarcely possible to penetrate the earth to a considerable depth anywhere within the Paleozoic area (except the rocks are highly contorted) without getting some natural gas, but the *large* supplies are confined to restricted areas, and it was to prevent the waste of capital in an indiscriminate search for these great stores of valuable fuel that prompted my original article on the subject. The drill will, of course, finally settle the question as to whether or not my conclusions were valid. Something, however, has already been accomplished in this line.

"A map of Ohio would reveal the same condition of affairs, for there are only two or three prominent anticlinals in the state, and after the expenditure of a vast amount of money in drilling, the only large gas wells have been found along these lines of *disturbance*. Kentucky, Illinois and West Virginia tell the same story; so that there would seem to be no good reason for any one longer to doubt that *structure* is the great factor in securing large and lasting gas wells.

"If, however, some skeptical capitalist shall ever find large gas wells, free from water, in a genuine syncline, like that at Greensburg, Pennsylvania, or at the bottom of the trough near Irwin, then I shall frankly confess that my judgment has been imposed upon. and that *geological structure* can give no clue to this hidden treasure.

"The reasons why the gas should be stored most abundantly along the arches are so patent that it is unnecessary to state them; the insoluble problem would be how to imprison large quantities of gas in a syncline, except what little might exist in water under high pressure.

"If our main proposition be true, viz. that the principal supplies of natural gas have been stored along the *arches* of the rocks, then the question of *location* must have a very important bearing upon the life of any particular gas field; for whatever may have been the source or origin of the gas, whether as a by-product in the genesis of oil (as much of it certainly is), or from the action of heated saline water on carbonaceous material, thus originating the Murraysville or odorless gas without any oil, as some claim, or in what way soever it is produced, the wells along the arches would have a much longer lease of life.

"Mr. Carll has recently sounded a note of warning through the columns of *The Petroleum Age*, to which those who think the supply inexhaustible would do well to take heed; for certain it is that many wells once large have long since ceased to flow. It is true that many of these have been choked up with salt because the water was not cased off, and the casing having been taken out, a column of water many hundred feet high has imprisoned others, but there is reason for believing that still others have failed because the source of supply was exhausted. On the 'anticlinal theory,' it would be expected that all wells not situated near prominent arches, nor at the upturned ends of vanishing synclines, could not have a long life, since the contents of the reservoir upon which they can draw must necessarily be of limited extent. But not so with those situated along the prominent arches, like that at Cannonsburg, Murraysville and Grapeville; for here the quantity in any one sand will be vastly greater than where the rocks are undisturbed, and the disturbance itself will have fractured the rocks and thus given access to many other reservoirs below the one from which the well draws immediately.

"The first Murraysville well has been delivering from fifteen to twenty million feet of gas daily for nearly ten years, and yet, with many other wells in close proximity, its volume has not yet been appreciably diminished. Hence there is good reason for believing that the gas wells situated on the prominent arches may have

a much longer life than others not so fortunately placed, and that the immense amount of capital invested in pipe lines to them will receive an adequate return before the gas shall have been exhausted. Nothing but time can determine the life of gas territory situated upon a well developed arch, like the Murraysville or Saltsburg anticlines.

"In Washington county, Pennsylvania, there are three principal geological horizons at which large supplies of gas are found, and, taking the Pittsburg coal as a datum line, these horizons come in as follows, neglecting fractions:

	Feet.
First horizon, below Pittsburg coal	900
Second " " " "	1,800
Third " " " "	2,000

"The *first* horizon furnishes a gas very much like the Murraysville gas, and the pressure seldom rises above 300 pounds to the square inch. It is contained in the no. XII conglomerate, since the rock lies about 200 feet above the Subcarboniferous limestone.

"The *second* horizon is identical with the first Venango oil sand, and seems to be the gas horizon *par excellence* of southwestern Pennsylvania, since it is also the great producing rock in Beaver, Alleghany, Butler and Westmoreland counties. It is nearly always overlain by a dark, close slate, which has evidently been a factor in enabling the rock to retain the gas. The product of this rock is strongly scented with petroleum in Washington county, but at Murraysville and Grapeville, in Westmoreland, it is nearly odorless, though it is oil-scented again near Latrobe.

"This same rock is the gas reservoir at Wellsburg, West Virginia, and has there been identified by Professor Orton as the Macksburg oil sand, which he in turn identifies with the Berea grit.

"The *third* great gas horizon of Washington county is in the 'stray,' or uppermost member of the third Venango oil sand. The famous McGuigan well is in this sand, as also the Donaldson, Willison, McClean, and others in Washington county.

"The total pressure to which the gas from this rock will rise, when shut in, has never been determined, so far as I am aware, but it would probably exceed that from the first Venango, or Murraysville sand, which seldom rises above 650 pounds to the square inch.

"The explanation of gas pressure in any particular rock seems as yet quite obscure, but there is evidently an increase of pressure with increase of depth, though the law of increase (if there be any law) is not uniform. For instance, the wells at Erie which go down 600 to 700 feet, show a maximum of only 40 to 50 pounds. Mr. Westinghouse, of the Philadelphia company, Pittsburg, suggests that the gas pressure in any case may be due to the water, or hydrostatic pressure on the rock, and this is possibly true, since it would account for the greater pressure as the sand gets deeper below the surface."

Since the above statements with reference to the Washington county gas horizons were written the drill has developed two others, viz, one in the "Big sand," or Manifold farm oil rock, which begins directly under the Mountain or no. XI limestone, and is 250 feet thick. This rock is the upper member of the Pocono sandstone, and is called in Ohio the "salt sand." The horizon in it which furnishes gas is about 1,150 feet below the Pittsburg coal.

The other gas horizon is the so-called "50-foot rock," which has proved so prolific in oil at the Smith no. 1. The top of this sand comes about 1,850 feet below the Pittsburg coal, and it is very probably identical with the second Venango oil sand.

THE CRITICISMS OF THE "ANTICLINAL THEORY" OF NATURAL GAS.*

READ AT THE BUFFALO MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, AUGUST, 1886, BY I. C. WHITE.

Through inexcusable carelessness (for I cannot be so uncharitable as to charge intentional misrepresentation), the critics of the "anticlinal theory" of natural gas have invariably misapprehended its claims, and criticised something other than this theory as held and promulgated by the writer.

My critics have almost invariably written about the theory as though it had been claimed that large gas wells could be found everywhere on every anticlinal roll, and in no other situation whatever. Messrs. Ashburner, Chance and Carll, of the Pennsylvania survey, have all set up for themselves this "man of straw," and of course easily demolished him, since no one with whom I have any acquaintance has ever held or published any such theory of natural gas occurrence as they combat. The eminent director of the Pennsylvania geological survey, in his presidential address at Ann Arbor last year, found occasion to refer to the "exploded anticlinal theory of natural gas" as a splendid piece of "dead work," accomplished presumably by the critics already mentioned. It is true that this "dead work" has effectually buried the anticlinal theory as put forth by these critics, for neither the writer nor any one else ever held such a theory; but substantially all that I have ever claimed for it has now been so thoroughly established by the "live work" of the drill, that no geologist, well informed on the subject, will be so rash as to deny the fact.

The gentlemen who have so freely criticised the "anticlinal theory" seem to have stopped reading my first paper on the subject, in *Science* of June 26, 1885, when they came to the *limitations* placed on the theory. On no other hypothesis can I understand the grounds of their opposition. Those who have interest enough in the matter to desire to read my papers on the subject will find all of them in the "Natural Gas supplement" of the *American Manufacturer;* and after having done so, they will find that the essence of it all is, that the great supplies of natural gas have accumulated in the rock reservoirs, in regions of disturbance by which the reservoirs in question have been elevated above contiguous areas of the same beds, and in the lower levels of which oil and water may be expected; or, in other words, gas has accumulated where anticlinals or monoclinals of considerable (but not too great) extent have raised the rocks into arches and other forms of elevation; and hence, as Professor Orton says, *structure* is the main element in the occurrence of gas and oil in large quantity.

The theory teaches that it is useless to bore for large gas supplies in a region where there are no considerable or irregular dips, and hence its negative value is of great importance, since in my own experience but a single failure has been made in condemning such regions; and if any further proof was needed, the larger portion of the state of Ohio bears unmistakable testimony to the negative value of the "anticlinal theory."

But probably the strongest testimony in favor of this theory is the almost universal approval of the practical operators. Many of these, I find, have been guiding their own operations on the same principle for many years, and I very much doubt whether a single operator in Pennsylvania could be induced to drill for gas in a well marked syncline.

*Read by title only at the meeting of the A. A. A. S. in Buffalo, August, 1886; subsequently published in *The Petroleum Age* for November, 1886 (vol. v, pp. 1161, 1165), from which it is reprinted.

The great gas fields of Washington and Grapeville, which the writer located on this theory, are sufficient evidence to most people that its claims are not entirely delusive, or the result of coincidence, as my friend Ashburner would have us believe.

A map which the writer prepared to accompany an article on natural gas in *The Petroleum Age* has also been a source of trouble to some of my former associates on the Pennsylvania geological survey. One in particular says some very unkind things about it: First, that the scale is too small; second, that the anticlinals are incorrectly placed; and, thirdly, that Mr. Ashburner's "great" Kinzua-Emporium cross-cut anticlinal is a myth, as likewise all the others, both "great" and small, which appear on the map in question.

As to the first count in this indictment, I claim exemption from blame, for the original map prepared for this purpose was on a scale of six miles to the inch, instead of ten, as published, and the editors of the *Age* will bear witness that I desired the larger scale, which they declined to publish on account of expense.

As to the second count, I would say that the mechanical execution of the map was committed to Messrs. Johnson and Grafton, two young engineers and experienced draftsmen, who put the anticlinals on the map from data furnished by the publications of the Pennsylvania geological survey, except, as stated in my accompanying paper, I took the liberty of correcting some of my own work from later and more detailed observations in the southwestern part of the state; and hence, if any serious error exists in the placing of the anticlinals, it is not the fault of the writer.

With regard to the last count, the writer pleads that he did not invent the term "cross-cut anticlinal," since, in the paper to which reference has been made, he gives due credit to its author and discoverer, Mr. Ashburner. If the black line which has been stereotyped so long on the McKean, Elk and Cameron county maps of the Pennsylvania geological survey, under the name of "Kinzua-Emporium cross-cut anticlinal," is really a myth, as Mr. Ashburner himself seems now not unwilling to admit, then the writer shall certainly raise no objections to having the term erased from geological nomenclature, as well as from the maps in question; but the structure that the writer described under this term will not be changed by a change of name.

As is well known, the main anticlinals of western Pennsylvania extend in a northeast-and-southwest direction, and, as a general rule, the rocks dip down to the southwest along the lines of the anticlinals as well as those of the synclinals; but in some regions, notably at Washington and Grapeville, there is such a swelling up of the anticlinals that the rocks *rise* rapidly to the southwest instead of *dip*, and as some of these *bulges* on the different anticlinals are in a line with each other, I thought it not improbable that they might be connected in origin at least, and hence, having no other name at hand, adopted the one already coined by Mr. Ashburner for what I supposed represented a similar structure.

But whatever we may call the structure in question, whether a *swell*, *bulge*, or "*hog-back*," as one gentleman terms it, the localities where it occurs are those *par excellence* where we may expect large deposits of natural gas; and when large wells have been obtained in the trend of a syncline the structure is found to be complicated by the presence of such a *bulge*, or else a long and rapid rise from the southwest.

The writer knows that the anticlinal theory, taken in connection with the *limitations*, which are a necessary part of it, is a valuable guide to the geologist in search of natural gas deposits, because he speaks from an experience of more than three years, in which the theory has been put to many practical tests.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 217-218 APRIL 15, 1892

FOSSIL PLANTS FROM THE WICHITA OR PERMIAN BEDS OF TEXAS.

BY I. C. WHITE.

In the spring of the present year, Mr. E. T. Dumble, state geologist of Texas, sent me for examination a small collection of fossil plants from the Wichita beds of that state.

These plants were discovered and collected by Mr. W. F. Cummins, assistant on the Texas survey. They occur in the Wichita beds along with invertebrate remains which Dr. C. A. White has assigned to a Permain age, and vertebrate remains which Professor Cope asserts are of the same age. I was therefore quite anxious to know what answer the plants might give to the question of supposed geological equivalency between the Wichita series of deposits and those at the summit of the Carboniferous column in southwestern Pennsylvania and West Virginia and in southern Ohio, where the invertebrate and reptilian remains are absent, or at least not yet discovered, though plant remains are abundant.

These West Virginia beds above the horizon of the Waynesburg coal had long ago (1878) been referred to the Permian by Professor Wm. M. Fontaine and myself.* upon the evidence of the fossil plants found therein: but as the correctness of this reference had been questioned, or at least not generally recognized by American geologists, the opportunity to compare this flora with that of a locality containing a Permian fauna, through the kindness of Mr. Dumble, was heartily welcomed.

After such cursory examination as I could give the plants when first received, I saw at a glance that they were either identical with, or very near relatives of, our West Virginia plants from the beds above the Waynesburg coal, and so wrote Mr. Dumble at the time. But to be certain of the matter, I sent the plants to Professor Wm. M. Fontaine, the distinguished paleobotanist at the university of Virginia, who at my request examined the collection and sent me the following list of identifiable species:

* PP, Pennsylvania Second Geological Survey.

Sphenophyllum latifolium, F. & W.	*Pecopteris lanceolata*, F. & W.
" *filiculme*, Lx.	" *platynerris*, F. & W.
Annularia, near *radiata*, Brt.	" *latifolia*, F. & W.
Walchia, sp.?	" *imbricata*, F. & W.
Odontopteris nervosa, F. &. W.	" *tenuinerris*, F. & W.
Callipteris conferta, Brt.	" *schimperiana*, F. & W.
Callipteridium oblongifolium, F. & W.	" *rotundifolia*, F. & W.
" *dawsonianum*, F. & W.	" *candolleana*, F. & W.
" *grandifolium*, F. & W.	*Goniopteris oblonga*, F. & W.
" *unitum*, F. & W.	

A few other new or indeterminable forms were present, one badly preserved specimen resembling *Lepidodendron*.

Professor Fontaine appends the following remarks concerning the geological horizon of the plants in question:

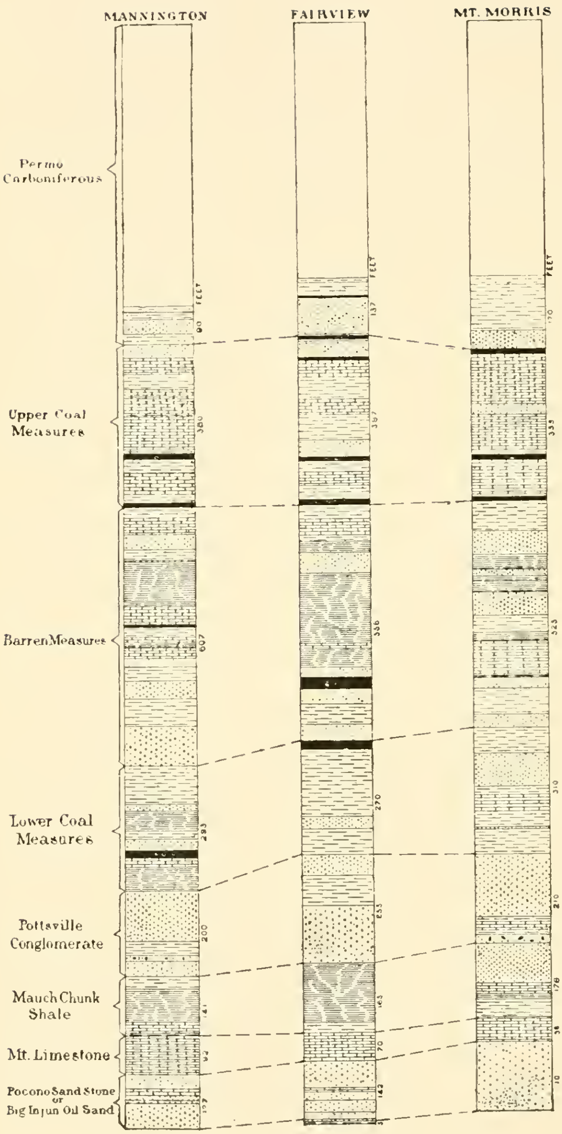
"I am decidedly of the opinion that this Texas flora is essentially the same with the flora described by us in report PP of the second geological survey of Pennsylvania. The *Walchia* is the only important determinable plant not present in the flora of West Virginia and Pennsylvania."

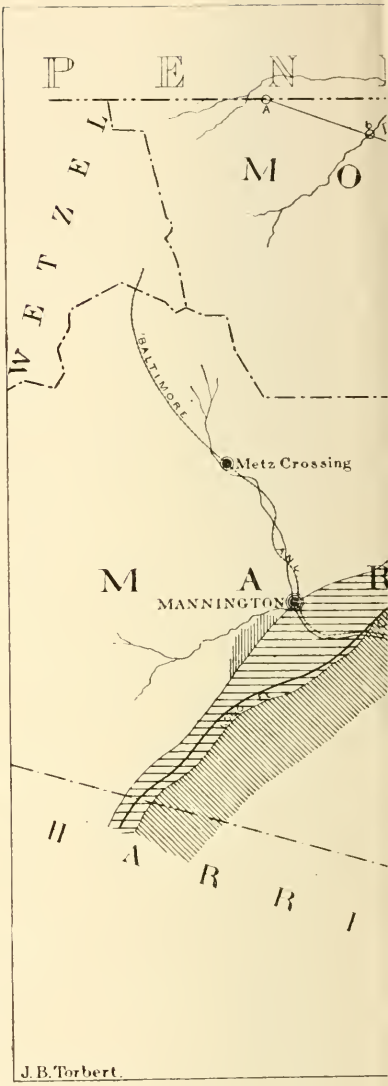
This conclusion of Professor Fontaine exactly confirms my own as given in Bulletin 65, United States Geological Survey, page 42, before I had seen the plants in question.

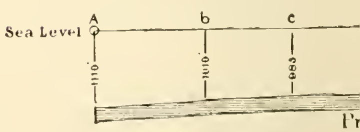
It follows from the evidence of this list of plants, as well as from general stratigraphic facts, that the age of these uppermost rocks of the Carboniferous system in West Virginia, southwestern Pennsylvania and southern Ohio, or the Dunkard Creek series,* as I have termed these deposits above the horizon of the Waynesburg coal, is the same as that of the Wichita beds of Texas; and if the latter be referable to the Permian on the basis of their reptilian and invertebrate remains, then geologists can no longer refuse to recognize the Permian age of the Dunkard Creek series, since, as shown by the list given above, every determinable plant sent me from the Wichita Series except one (*Walchia*) has been found in the Dunkard Creek beds.

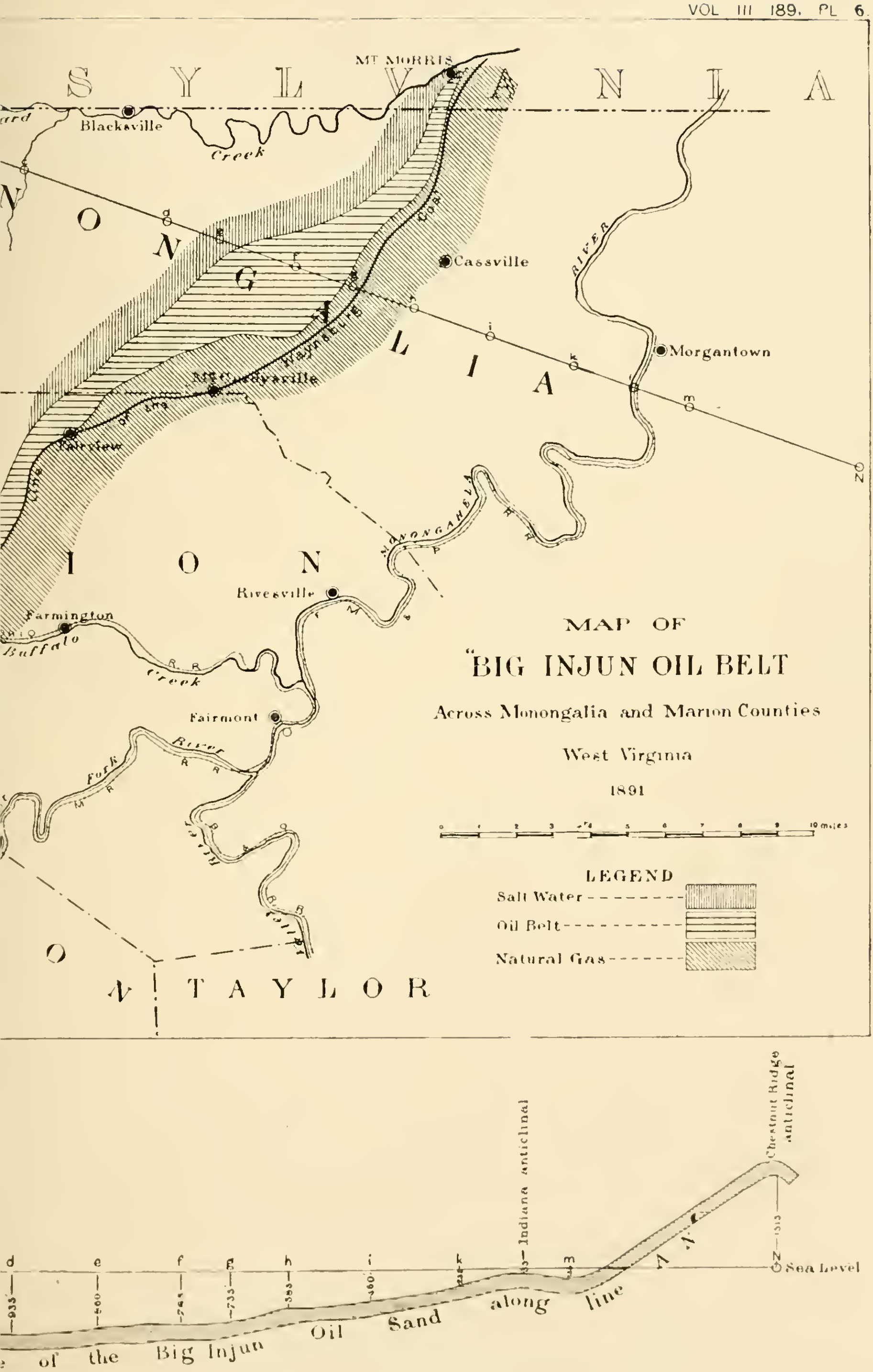
The plants of this list were collected by Mr. Cummins from the upper portion of the Wichita at the head of Godwins creek, Baylor county, Texas, and from three miles west of Antelope, Texas.

* Bulletin 65, U. S. Geol. Survey, 1891, p. 20.


MANNINGTON
FAIRVIEW
MT. MORRIS
Permo Carboniferous
Upper Coal Measures
Barren Measures
Lower Coal Measures
Pottsville Conglomerate
Mauch Chunk Shale
Mt. Limestone
Pocono Sand Stone or Big Injun Oil Sand
FEET


P E N
W E T Z E L
M O
BALTIMORE
Metz Crossing
M A
MANNINGTON
H A R R I
J. B. Torbert.


Sea Level
A
b
c


MAP OF
"BIG INJUN OIL BELT
Across Monongalia and Marion Counties
West Virginia
1891
LEGEND
Salt Water
Oil Belt
Natural Gas
MT MORRIS
Blacksville
Cassville
Morgantown
Mt Morris
Fairview
Farmington
Rivesville
Fairmont
TAYLOR
Monongahela River
Buffalo Creek
Sea Level
Indiana anticlinal
Chestnut Ridge anticlinal
of the Big Injun Oil Sand along line

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 219-230

NOTES ON THE GEOLOGY OF THE VALLEY OF THE MIDDLE RIO GRANDE

BY

E. T. DUMBLE

ROCHESTER
PUBLISHED BY THE SOCIETY
APRIL, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 219-230 APRIL 22, 1892

NOTES ON THE GEOLOGY OF THE VALLEY OF THE MIDDLE RIO GRANDE.

BY E. T. DUMBLE.

(Presented before the Society December 31, 1892.)

CONTENTS.

INTRODUCTION.

The following statements are based partly on observations made during a trip from Eagle Pass to Edinburg by row-boat in the months of May and June, 1889, and partly on work in the region between Del Rio and Eagle Pass during the summer of 1891.*

A portion of the area having been described by Dr. R. A. F. Penrose, Jr., in the first annual report of the Geological Survey of Texas, in the present article I propose to confine myself to that part of the river between San Felipe creek, near Del Rio, and Webb bluff, three miles below the southern line of Maverick county. A line joining the two

*The greater portion of the section above Eagle Pass was made in company with Mr. J. Owen, who rendered valuable assistance by his accurate knowledge of the region on both sides of the Rio Grande.

points has a direction S. 27° E., and a length of 81.7 miles. The distance by the river is probably half as much more, or one hundred and twenty miles. The general direction of the dip is about S. 45° E., which in this region of very slightly inclined strata makes the section practically follow the dip.

Topography.

For the distance given, the Rio Grande flows in a valley eroded in Quaternary (or later Tertiary) and upper Cretaceous sediments, and its banks vary in character with the different materials of which they are composed. When the strata are of sufficient hardness, bluffs of from 50 to 100 feet in height are found stretching along on one side or the other of the river, while opposite there is generally only a gentle slope from the water. In places the line of hills drops back some three or four miles from the river, leaving broad fertile valleys. The general nature of the topography, while resembling that of the same formations in central Texas, is characterized by somewhat more angular and stronger lines, due, no doubt, to the difference in climatic conditions. The tributaries which empty into the Rio Grande on the Texas side are mostly small and carry comparatively little water. The principal creeks are San Felipe, Sacatosa, Sycamore or San Pedro, Pedro Pinto, Cow, Texaquito, Las Moras, Elm, Rosita, Willow and Cuero. On the Mexican side, however, there are bold streams which add considerably to the volume of water in the river. Among them are the San Diego, Escondido and San Domingo rivers.

The elevation of Del Rio, according to the Southern Pacific railroad engineers, is 973 feet; that of Eagle Pass, by the same authority, is 762 feet. According to a line of levels run for an irrigating canal, the bed of the river is 120 feet lower at Eagle Pass than at the falls some forty miles above, giving about three feet fall per mile in direct line, or about two feet per mile of river. All of the falls and rapids, which are numerous, are caused by the edges of the harder strata as they are carried under by the dip.

Geologic Structure.

lower cretaceous.

The town of Del Rio is situated on the *Arietina* clays, which have here a great development. Just southeast of the town there is a conical hill or "mountain" 100 feet, or possibly more, in height, composed of clays and shales and containing great numbers of shells of *Exogyra arietina*, Roemer, *Nodosaria texana*, Conrad, and various other fossils. The hill

is capped by gravel. Toward the south and east rises a scarp composed of the same *Arietina* clays and *Nodosaria* shales.

The deposits of ochre which have been reported from this district occur in these *Arietina* clays in the form of segregations of ferruginous matter in bodies of considerable size but somewhat variable quality.

The clays and shales of the scarp are capped by a fine grained sub-crystalline limestone of creamy white color, semi-conchoidal fracture, and containing many small reddish spots. This limestone is lithologically and stratigraphically equivalent to the *Vola* limestone of the Colorado section, and although no fossils have been found, it is referred to that horizon on these grounds alone. It is the highest bed of the lower Cretaceous in this locality.

UPPER CRETACEOUS.

The Val Verde Flags.—The lower Cretaceous materials continue to a point 2½ miles south of Del Rio, where the *Vola* limestone is overlain by a softer flaggy limestone. The contact observed in this locality was so small in area and so covered that no conclusion could be reached regarding the conformity of the two beds. Where it has been observed in other localities it shows little, if any, unconformity. The lime flags can be followed to Sacatosa creek, 6 miles southeast of Del Rio, where they are well developed. They are grayish-white in color, laminated to flaggy in structure, and separated into bands by laminated clays. The lower strata contain considerable bituminous matter and the remains of fishes. The higher beds of this locality are also sufficiently bituminous to give off a fetid odor when struck with a hammer. The principal fossil here is *Inoceramus*, the species of which have not yet been determined. These flags can be followed from this locality down Sacatosa (?) creek to the Rio Grande, and down the Rio Grande to Sycamore creek, forming a bluff 25 to 75 feet in height along the river the entire distance, so that we have an exposure some six miles in length along the line of section, with a dip apparently not less than 100 feet to the mile.

These bluffs are in Val Verde county, and for that reason I have named the flags the *Val Verde flags*. They are tolerably uniform in structure from base to top, the principal variation being in thickness. In places they are shaly, but are commonly flags of various thicknesses, frequently showing on a transverse surface alternate parallel laminæ of white and yellow. Their weathered surfaces are from light yellow to reddish, and in some places beds of deeper yellow or even orange hue are found. Moderate amounts of oxide of iron occur, and at one place a quantity of calcite was observed crystallized similarly to that which I

have described from Anderson county.* In some localities, especially on the Mexican side, the ferruginous coloration appears on the flat surfaces of the flags in beautiful grainings, many specimens of which can be seen in Eagle Pass and Porferio Diaz. The only fossils which I found were different species of *Inoceramus*, except toward the top where a few small ammonites were seen; but it is possible that others may be obtained on closer examination.

A thin seam of lignitic matter was observed in the flags at the mouth of Sycamore creek, on the southern side of the bluffs.†

The Pinto Limestone.—Sycamore creek flows at the base of the Val Verde bluffs, which at its mouth turn sharply northeastward and, after running back from the river for several miles, turn southeastward again, and then run back toward the river, leaving a valley along the Texas side some 4 miles or more in width. At the southeastern point of the bluff on Sycamore creek the contact of the Val Verde flags with the base of the overlying chalky limestone is found. The difference in the physical character of the two limestones is very marked. The flags show their laminated character throughout, while the overlying limestone is of earthy texture and without any perceptible lamination. The beds of the upper limestone vary in thickness from one to three feet or more and are separated by bands of laminated limy shales. The thickness of the overlying limestone at this point is not more than 12 or 15 feet. The fossils observed belong to the genera *Inoceramus* and *Ammonites*.

These bluffs, in common with all others in this vicinity, are capped with 20 to 30 feet of gravel or chalky conglomerate belonging to the Reynosa beds.

Crossing the valley we find the bluffs at its southern margin on Pinto creek to be of chalky limestones separated by limy clays in bands from one to two feet in thickness, the whole exposure being about 30 feet in height. The only peculiarity noticed was numerous grooves cut in the limestone, extending diagonally across the present creek bed and very nearly in the general direction of the flow of the Rio Grande,

On the Mexican side of the river, between these two points, a long line of bluffs appears, showing the limestone resting on the flags with apparently a slight difference in dip between them, the dip of the flags being seemingly somewhat greater than that of the overlying limestone. At the southern extremity of this line of bluffs the limestone is in heavier beds (three feet or over) and rises to a height of 40 feet or more above the river. Some cavities of considerable size have been weathered in it.

---

* 2d Ann. Rep. Geol. Surv. of Texas, 1890, p. 305.

† Mr. Owen informs me that these flags attain a very much greater thickness toward the southwest in Mexico.

Opposite the extremity of the line of bluffs, on the Mexican side and a short distance above Piedro Pinto creek, the Rio Grande turns abruptly westward, and for a quarter of a mile flows in rapids over the edges of underlying limestone. It is here that the water is to be taken out for irrigating the valley north of Eagle Pass, which contains about forty thousand acres of irrigable land. The exposures of the limestone continue from here to Las Moras creek, a total distance of 15 miles from its first appearance. The following sections will show its character:

Cow Creek Section.

	Feet.
1. Thick-bedded limestones, with interbeddings of clay shales and nodules of altered pyrites	40
2. Similar limestones in thinner beds	35 or 40
Fossils.—Inoceramus, Gryphæa, Ammonites, Baculites, of undetermined species; fossils sometimes ferruginated.	

Texaquito Creek Section.

1. Gravel, with calcareous cement (Reynosa beds)	
2. Bowldery limestone containing numerous shells of *Exogyra ponderosa,* Roemer	6
3. Chalky limestone	6
4. Softer limestones of similar character, with several species of *Inoceramus* and other fossils	6
5. Yellow bowldery limestone in beds separated by bands of limy clay; the limestone becomes more chalky in appearance toward the base (upper *Gryphæa* bed, characterized by *Gryphæa aucella,* Roemer, which is very abundant toward the base, but disappears toward the top)	16
6. Harder limestone, much broken, with shales and limy clays	25
7. Obscured by later gravel	20
8. Limy clay, with great numbers of shells of *Exogyra costata* and *Inoceramus,* sp. und	
9. Yellow limy shales, with same fossils as number 8, and containing ferruginous seam	4
10. Clayey limestone, with a large *Ammonites* (14 inches in diameter). *Nautilus,* sp. nov., and immense *Inoceramus* shells. This limestone is bedded in strata twelve to fourteen inches in thickness and strongly jointed. The compass bearing of joint planes is N. 20° E., and the lines contain oxide of iron. The *Inoceramus* here, as elsewhere, is preserved in two ways: In one they are simply molds showing the outer form of one or both shells; in the other, shell fragments and sometimes entire shells occur. Specimens were measured having a length of 15 inches	25

Las Moras Section.

1. Gravel, chalky limestone, with some iron pyrites. *Inoceramus* of several species, *Nautilus, Ammonites, Baculites,* etc., to creek	4

This section is at road crossing of the creek, half a mile from the Rio Grande. At the mouth of the creek the limestone passes under the water, and just below is succeeded by the beds of the Eagle Pass division. The contact is covered by river drift, but may be found further up the creek.

Throughout the entire range of this chalky limestone the conditions of deposition seem to have been quite similar. The beds become somewhat more massive but broken toward the top. They are separated by limy shales at the base, then by calcareous clays, then by purer clays, and finally by calcareous clays again. *Inoceramus* and *Ammonites* seem to be the only fossils ranging entirely through the Val Verde flags and Pinto limestone, and the occurrence of *Exogyra ponderosa* and *E. costata* so far down in the Pinto limestone is worthy of note.

The Eagle Pass Division.—Immediately overlying the Pinto limestone there is a great series of clays, sands and greensands, with more or less impure limestone and beds of coal, to which I propose to give the name *Eagle Pass division.* This name was suggested for a portion of these deposits by Dr. C. A. White in 1887, and I now extend it to cover the entire series of deposits lying above the Pinto limestone and below the Webb bluff beds. It has a surface exposure along our line of section of nearly sixty miles. It comprises a number of more or less distinct members which may be described separately.

Upson Clays.—The basal member consists of yellow clay containing calcareous nodules of septarian character, the crevices or septæ of which are filled with dogtooth spar. These nodules occur in large geodic forms scattered through the clays, and contain *Exogyra ponderosa*, Roemer. Numbers of specimens of these fossils are found in geodes as well as on the hillsides, where they have been left by the disintegration of their matrix. The nodules or geodes seem to occupy pretty definite horizons, and sometimes form benches on the hillsides. The uppermost member of this series, as I observed it, is a clay shale.

San Miguel Beds.—Resting on the clay shales, which form the upper member of the Upson clays, there is a deposit of sandstone, thin to heavy bedded, separated by bands of clay, and containing seams of glauconitic material with many fossils, as well as occasional heavy beds of clay, especially toward the top. I have called this deposit the *San Miguel beds* from the locality at which it was first observed by Dr. Comstock and myself. In the Rio Grande section it first occurs in the hills north of Carter's ranch, where the hills show exposures of it from 75 to 100 feet in height. The exposures are excellent for several miles south of this point, and a very rich fauna, which is now being studied, was secured.

In the upper portion I found *Exogyra ponderosa*, and great numbers of other shells not yet determined. Above this the sandstone becomes more calcareous, and in places is compacted and contains calcareous nodules. Three miles south of Carter's ranch we found the teeth and bones of a saurian in the concretions. The materials overlying this become more clayey, as will be seen by the following section, made some 10 miles north of Eagle Pass:

Section near Eagle Pass.

	Feet.
Sand and silt	8
Sandstone	2
Clays displaying cone-in-cone structure	6
Sandstone with laminæ and nodules of calcite	1
Clay, to base	8

Above this there are sands with lime and greensand containing many casts of fossils, *Inoceramus* and other bivalves, together with numerous gasteropods. This continues to a point about 8 miles north of Eagle Pass, below which these strata are soon covered by the next newer series of deposits.

The Coal Series.—This series comprises the ferruginous shales, brown calcareous shales, brown calcareous clays, heavy bedded sands, shales, sands, and yellow clay which accompany the coal seam worked at the Hartz and other mines.

The exposures along the river above the Hartz mine show the following strata underlying the Reynosa beds of gravel and limestone:

Section near the Hartz Mine.

	Feet.
Brown calcareous clays	40
Ferruginated shales	40
Uncompacted sands*	20
Shale	20
Heavy bedded sands	30
Yellow clay†	20
Coal†	4
Purple shale†	6
Sand to river†	

Just south of the Hartz mine there may be seen the only disturbance of any considerable extent which was noticed in the entire section north

* Western extremity of coal seam.

† Exposed just above Hartz mine.

of Eagle Pass. This is a fault with a downthrow toward the north of about 60 feet.

Half a mile below the bridge across Elm creek the following section was observed:

Section on Elm Creek.

	Feet.
Sand	12
Gravel	1 to 4
Nodules of oxide of iron	½ to 1
Sand	2
Chocolate clays, with interbedded iron nodules	3
Cross-bedded sandstone	1
Blue clay	1
Sandstone containing clay inclusions, some glauconite, and regularly stratified iron nodules	3
Clays with very thin seam of coal	

Above the bridge a deposit of shaly sands occurs, containing ferruginous sandstone seams which in places pass into a lean iron ore and form a stratum of eight to twenty inches in thickness. The sandstone has a very shaly appearance on weathering. Overlying this there are beds of laminated yellow clays, followed by darker beds with a very thin seam of coal.

Immediately above the laminated clays lies the stratum containing cannon-ball concretions, which, with the overlying sands carrying great quantities of silicified wood, form one of the most persistent and easily recognizable horizons of the series. There are numerous excellent exposures of the latter on Seco creek.

Convent Hill Section.

	Feet.
Gravel (Reynosa beds)	
Yellow clays and sands	30
Calcareous nodules, highly ferruginous, imbedded in clay	1 to 2
Bituminous shales with ½-inch seam of coal, to river	

Above these beds are found a series of brown or buff sandstones, semi-indurated, calcareous, and containing fossil shells of *Inoceramus*, *Exogyra ponderosa*, etc.

The entire section from these sandstones to the lower San Miguel sandstones is shown in a general way in the following record of a boring made for artesian water on the top of the hills just northeast of Eagle Pass:

Eagle Pass Artesian Well Section.

	Feet.
1. Soil and subsoil	14
2. Yellow clay	26
3. Bluish clay	50
4. Sand with some gravel	110
5. Black shale; six inches coal	60
6. Clayey sand	70
7. Gray sand	30
8. Sand; small gravel	60
9. Sand	20
10. Gray slate	30
11. Dark shale	55
12. Coal	6
13. Dark shales	9
14. White sand; gas	40
15. Black shale	150
16. Sand and shale	15
17. Black shale	135
18. Sand and shale; gas	15
19. Dark soft sand and shale	75
20. Hard gray sand; salt water	10
21. Gray shale	50
22. Gray sand	10
23. Calcareous clay	370
24. Dark clay	102
Total	1,512

This is important as giving us the relative dip of the beds. The coal seam which crops out 5 miles above Eagle Pass is found here at a depth of 525 feet, while at 1,512 feet the heavy sandstones which were noted 3 miles north of Carter's ranch, or 15 miles above Eagle Pass, have not yet been reached. The estimate of dip at 100 feet to the mile is therefore seemingly not at all excessive.

The materials below Eagle Pass are somewhat different from those above. The sandstones are harder and the clays have a blue or greenish hue; the lime, instead of being in the form of geodes or septaria, is intermingled with the sand, or forms separate strata; and the fossils are much more plentiful than in any other division except the San Miguel beds. I propose to call this deposit the *Escondido beds.*

Escondido Beds.—The last exposures of the Coal series beds on the river are at Porferio Diaz, where a greenish sandy clay with glauconite was observed, and a mile below, on the same side of the river, where there is a similar bed of sandy clay with indurated bowlders, streaks of lignite, impressions of leaves (grasses), and logs of silicified wood. At the mouth of Escondido river similar clay was seen, and a mile below there was

found a series of sandy clays capped by sandstones, with an indurated glauconitic layer containing small oysters and other fossil forms. This sandstone is the same as that capping the hills at Eagle Pass and is the lowest stratum of the Escondido beds.* Passing down the river this sandstone thickens and shows ripple markings in places, and has an apparent dip of at least 2°. The exposure is a mile in length, and consists of sandstones alternating with clays. Fossils are very abundant and well preserved, consisting of *Ammonites* (*Placenticeras*), oysters and other bivalves, and several gasteropods. Similar exposures continue for 4 miles below Eagle Pass. Above these come other blue clays and thin sandstones with many oysters.

At Fortress bluff, 6 miles below Eagle Pass, the exposure has a height of 60 feet, and is composed of sandstones with seams of sandy clay interstratified. The first of the great oyster beds occurs here in strata six inches to a foot in thickness. Similar exposures continue to the bluffs 10 miles from Eagle Pass. The sandstones at this locality are highly calcareous and contain several beds of oyster shells.

From this point to the falls of the Rio Grande, just above the Webb county line, the exposures are but repetitions one of another—brown, buff, blue, or green clays, with sandstones, sometimes friable and sometimes so indurated as to be semi-quartzites. Abundant fossils, consisting of *Ammonites* (*Placenticeras*), oysters and gasteropods, are found. The rapids (or falls of the Rio Grande), which continue almost to the line between the two counties, are formed by the edges of some of these ammonite-bearing beds as they pass below water level. From this point to Webb bluff, a distance of 3 miles, no fossils were found; but there was no change in the lithologic character of the rock materials, nor could the clays at the base of the Webb bluff section be distinguished in any way from those observed at the rapids above.

Webb Bluff Section.

	Feet.
Gravel	
Sandstone, white and glistening, with mica and some little iron; calcareous sandstones; clay with cannon-ball concretions; and small seam of grahamite	30
Greensand marls with many Tertiary fossils; nodules of carbonate of lime; specks of glauconite	7 to 8
Stiff, plastic dark greenish or blue clay, jointed	10

We have therefore only 3 miles in which there can be any room for deposits intermediate between strata containing fossils of recognized and

* From Mr. Owen's examinations I learn that this is a very persistent bed throughout Maverick county and is easily recognizable. It is about five hundred feet above the coal seam, and is therefore valuable as a definite horizon from which to work in prospecting for the coal.

decisively marine Cretaceous forms and those containing marine Eocene forms. The average dip does not exceed 100 feet per mile, and we saw nothing in any of the exposures on either bank of the river in this space to indicate a change until we reached Webb bluff itself. The entire appearance of the upper portion of this bluff was so different from that of the materials we had been examining for the three previous days that it was remarked even before we landed.

The upper Cretaceous Section.—If the estimated dip of 100 feet per mile can be relied on (and no evidence was found in the field work to cast any doubt upon it) the section as given would have a total thickness of over eight thousand feet, of which the upper Cretaceous deposits constitute about 7,800 feet, divided as follows:

		Feet.
Eagle Pass division	Escondido beds	3,300
	Coal series	900
	San Miguel beds	800
	Upson clays	700
Pinto limestones		1,500
Val Verde flags		600
		7,800

It may not be prudent, however, to rely implicitly upon the apparent dip in such materials as form the Escondido beds, because faulting might occur in places and be entirely unnoticed in such an examination as we could make. It is therefore possible that future work may somewhat reduce the estimate here given.

REYNOSA BEDS.

In May, 1889, I observed along the line of the Southern Pacific railway between San Antonio and Eagle Pass a deposit usually consisting of a larger or smaller quantity of gravel cemented by a very porous or tufaceous limestone. In some places the gravel seemed to be entirely missing and only the limestone present. The same deposit was noticed north of Eagle Pass on our visit to the coal mines, and we found it forming the summits of the hills at many localities along the river during our voyage from Eagle Pass to Edinburg. The thickness of this deposit as noted was from 3 to 30 feet, and in some instances it was overlain by the yellow silt flanking the Rio Grande. At the town of Reynosa (in the Mexican state of Tamaulipas) and opposite Edinburg in Texas we found a much larger and firmer deposit of limestone—the same indeed which was designated in the report of the Mexican boundary survey Cretaceous limestone. Our examinations resulted in finding

in it such fossils as *Bulimus alternatus*, Say, and in showing that it is stratigraphically higher than the Fayette sands. Dr. Penrose described it in the first annual report of the geologic survey of Texas under the name of the Reynosa limestone. The connection between this Reynosa limestone and the tufaceous lime and gravel, however, was not recognized until the past summer. Mr. J. A. Taff of the Texas survey, in his examination along the line of the Texas-Mexican railway between Corpus Christi and Laredo, observed the same lime and gravel with *Bulimus alternatus* overlying the Fayette sands at various places. I joined his party in Cotulla, and during my work with them up the valleys of the Nueces and Leona rivers I found many exposures of the gravel and lime and of the firmer limestone already described in such connection as to prove conclusively that they are mere local variations of one and the same deposit. I therefore extend the name Reynosa to include the entire series of deposits for the present. These deposits cover a very large area in western Texas and extend into Mexico. In places the limestone reaches such thickness and hardness as to be used as building material, as in the district south of Porferio Diaz, at Reynosa, and elsewhere. As nearly as we have been able to ascertain, these beds seem to be in part at least the equivalents of the *Equus* beds described by Professors Cope and Leidy in southwestern Texas. They appear to rest unconformably upon the underlying beds of Cretaceous, Eocene and Neocene age. While the connection of the Reynosa beds with the Lafayette formation toward the east has not been determined by actually tracing one into the other, their similar stratigraphic position above the Fayette sands and beneath the coastward clays of the Port Hudson (Columbia formation of McGee) is strong evidence in favor of their being different phases of the same formation.

CORRELATION OF RIO GRANDE AND COLORADO RIVER SECTIONS.

		Rio Grande Section.	*Colorado Section.*
Neocene		Reynosa beds	Lafayette (?)
Eocene		Webb Bluff Tertiary	Eocene
Upper Cretaceous	Eagle Pass division	Escondido beds	(Wanting)
		Coal series	(Wanting)
		San Miguel beds	Glauconitic beds
		Upson clays	*Ponderosa* marls
	Pinto limestone		Austin limestone
	Val Verde flags		Eagle Ford shales
Lower Cretaceous	*Vola* limestone		*Vola* limestone
	Arietina clays		*Arietina* clays

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 231-252, PL. 7

ELEOLITE-SYENITE OF LITCHFIELD, MAINE, AND HAWES' HORNBLENDE-SYENITE FROM RED HILL, NEW HAMPSHIRE

BY

W. S. BAYLEY

ROCHESTER
PUBLISHED BY THE SOCIETY
JUNE, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

Vol. 3, pp. 231-252, pl. 7 June 4, 1892

ELEOLITE-SYENITE OF LITCHFIELD, MAINE, AND HAWES' HORNBLENDE-SYENITE FROM RED HILL, NEW HAMPSHIRE.

BY W. S. BAYLEY.

(Read before the Society December 31, 1891.)

CONTENTS.

Introduction.

Of the two rocks whose petrographical descriptions are here given, one is from the well known occurrence near Litchfield, in Maine, and the other is the rock described by Hawes* as a hornblende-syenite from Red Hill, Moultonboro, New Hampshire.

In neither case has the writer examined the geological relations of the rocks sufficiently closely to warrant an expression of opinion regarding them. The New Hampshire locality has not been visited at all. The Maine occurrences have been visited twice, but on neither occasion were more than a few minutes spent at the several places where the rock is found.

The only excuses for the publication of this fragmentary paper at the present time are the interest that always pertains to the rare eleolite-

*G. W. Hawes: Min. and Lith. of New Hampshire, pt. iv of Geology of New Hampshire, Concord, 1878, p. 206.

syenites and the desire to put on record the discovery of another locality for them within the United States.

Thanks are due to Messrs H. K. Morrell of Gardiner and R. G. Clough of Monmouth, Maine, for valuable aid in the collection of specimens of the Maine rock, and to Mr. M. M. Smith of Deland, Florida, and Mr. W. H. Mason of Moultonboro for information respecting the New Hampshire locality and for abundant material from it. Mr. J. S. Diller and Dr. F. W. Clarke of the United States Geological Survey have also done all in their power to help make the descriptions as complete as possible under the circumstances, the former gentleman having furnished thin sections of both the Maine and the New Hampshire rocks, and the latter having kindly provided analyses of both. I desire to express my appreciation of their aid, and also to thank Mr. G. P. Merrill of the National Museum for a chip from Hawes' original specimen of the New Hampshire rock, and Messrs L. G. Eakins, W. H. Melville and W. F. Hillebrand for the careful chemical work that appears in the body of this article.

The Eleolite-Syenite of Litchfield and other Localities in Maine.

Distribution.—It is not quite certain that this rock has been found in place. Nearly all the specimens that have been sent abroad to the museums of this and other countries have come from bowlders or loose fragments lying on both sides of the road running from South Litchfield post-office, in the town of Litchfield, Kennebec county, Maine, to the city of Gardiner, on the Maine Central railway, about six miles south of Augusta. The distance of the locality from South Litchfield is about three-quarters of a mile, and from Gardiner about eight miles. Here the fragments and bowlders are often quite large. Some are half buried in the soil on the gradual slope of a hill, while others lie on the surface. From the great abundance of the bowlders and their large size, together with their thick accumulation in such a small area, it is argued by many competent geologists that the parent ledge is somewhere in the near vicinity. However this may be, there can be no doubt that the rock is a schistose eruptive. In large pieces the schistosity is quite apparent, and even in hand specimens it may sometimes be readily detected. The characteristic mineral of this occurrence is cancrinite. The other two localities in which cancrinite predominates over sodalite and eleolite are southeast of South Litchfield, on the farms of Messrs Sawyer and Spaulding (see map, figure 1). In both of these cases the rock is in the shape of bowlders. At Sawyer's several large ones lie on the surface south of the road and within sight of it; at Spaulding's broken fragments are found built into stone walls. The underlying rock at both places is quite different

from the eleolite-syenite, so that there is no probability of the latter being found at either place *in situ*. On the other hand, it is worthy of remark that the bowlders in both instances are directly in the course of the glacier* that passed over the region of South Litchfield.

Another well known locality, especially for that phase of the rock containing sodalite and large crystals of eleolite, is at Spears Corner, in West Gardiner, on the road from South Litchfield to Gardiner. On the

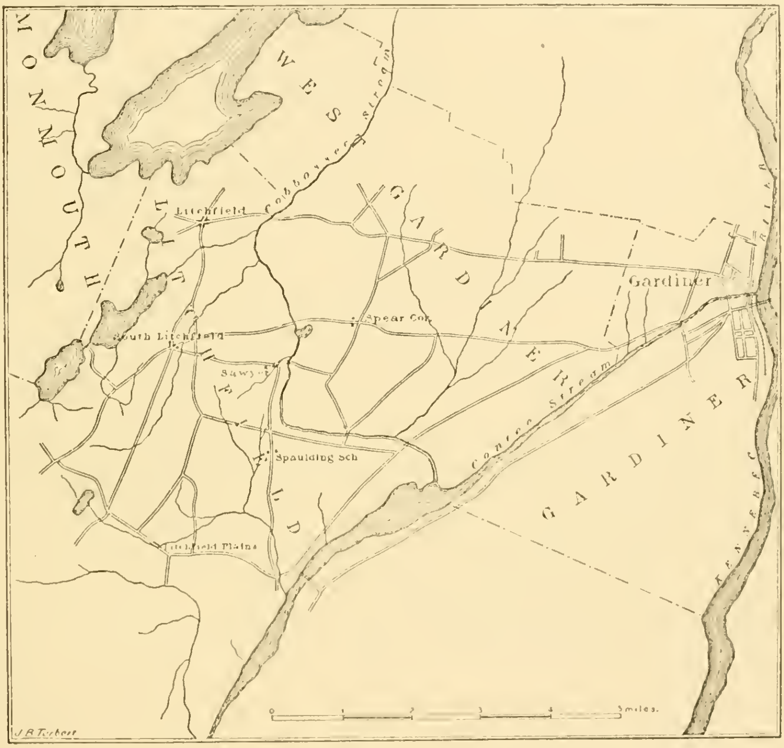


FIGURE 1—*Map showing Distribution of Eleolite-Syenite in the Towns of Litchfield and West Gardiner, Maine.*

northern side of the road and about one hundred yards from it, in a clump of bushes near the bottom of a hill, there is a pile of large blocks resembling in their general arrangement the heap at South Litchfield. Most of these were originally completely buried in the sand and soil They are now well exposed through the active operations of collectors, but the soil around them has not been sufficiently removed to enable us

*Cf. T. C. Chamberlin: Map of a Portion of the Terminal Moraine, in 3d Ann. Rep. U. S. Geol. Survey, 1883, pl. xxxiii.

to say positively whether the rock exists merely in bowlders or whether some of it may not be in place. A little north of east of South Litchfield the sodalite-bearing eleolite-syenite is again met with, on the eastern slope of a glacial ridge on the western side of the southern end of Cochnewagon pond in the town of Monmouth. Mr. Clough, who has carefully explored the region thereabout, asserts that the rock is found in a stretch of country running about northwest and southeast, with a width of only a few rods and a length of about two miles. Within these limits bowlders may be picked from any of the stone walls surrounding the fields. Beyond them the syenite has not yet been discovered. At Cochnewagon pond the bowlders of eleolite-syenite occur in considerable numbers with others of gneiss, granite and schist, principally at the base of a gravel and sand ridge that rests upon a foundation of slate. There is no question but that in this case the rock is not in place. It has undoubtedly been transported thither from somewhere toward the northwest.*

From a consideration of the statements above made, it would seem probable that all of the eleolite-syenite of the towns of West Gardiner, Litchfield and Monmouth has come from a region beyond the limits of these towns, and that nowhere within them does the rock occur in place.

Macroscopic Description.—The macroscopic appearance of the Maine eleolite-syenite is too well known to need much description. Its most noticeable features are the large masses of bright yellow cancrinite and deep blue sodalite and the brilliant plates of black mica that spot its otherwise almost snow-white surface. Here and there light brown zircon † crystals are imbedded among the other constituents, but they are by no means so numerous as museum specimens would seem to indicate. Among the lighter minerals that can be distinguished in the hand specimen, the most abundant is a white feldspar, often occurring in large columnar crystals from a quarter to a half inch in length. They have a distinct cleavage and a pearly luster on cleavage surfaces. Their specific gravity varies between 2.608 and 2.600. A partial analysis of pieces picked from a hand specimen is reported by Dr. Clarke ‡ to have yielded—

SiO_2	Al_2O_3	K_2O	Na_2O	H_2O	Undet.
66.39	19.69	0.99	10.17	0.52	(2.24)

This feldspar, which is undoubtedly albite, is the most prominent one in the rock, and is that which gives to it its characteristic peculiarities.

* Bowlders of the eleolite-syenite, sometimes containing cancrinite and at other times rich in sodalite, may also be found in almost any of the stone walls dividing the fields that lie within an area encompassed by lines joining the above described points.

† These zircons were analyzed by Gibbs (Pogg. Annalen, b. lxxi, 1822, p. 559) with the following result: $SiO_2 = 35.26$; $ZrO_2 = 63.33$; $Fe_2O_3 = .79$; undet. = .36.

‡ Am. Jour. Sci., 3d ser., vol. xxxi, 1886, p. 268.

Another of the prominent components is eleolite, which appears as irregularly shaped masses or as large columnar crystals with a length of as much as two inches and a breadth of half an inch. The irregular masses are distributed uniformly throughout the rock, while the crystals occur only in those portions in which the darker constituents are lacking (*i. e.*, in acid "Schlieren"). In both cases the mineral possesses a gray color and the characteristic oily luster of eleolite, while its cleavage cracks are marked by interpositions of long dark needles of a black mica. Dr. Clarke* reports the eleolite to contain—

SiO_2	Al_2O_3	CaO	MgO	K_2O	Na_2O	H_2O	Total
43.74	34.48	tr.	tr.	4.55	16.62	0.86	100.25

All the constituents above mentioned are usually imbedded in a fine sugary aggregate of feldspar, of which there are several varieties, as will be shown later. Occasionally this fine grained aggregate is in very large quantity, when it appears as a groundmass surrounding the coarser grains. More frequently it is in smaller or larger areas between the other components, and in rare cases it is entirely absent. In this latter event the rock is a coarse grained mixture of large albite and eleolite grains and plates of lepidomelane. Its structure is massive, while that of all other varieties is schistose. In these schistose phases the plane of schistosity, as shown by the lamellar arrangement of the mica plates, is parallel to the contact of the rock with a lepidomelane schist, that is probably nothing other than a very basic portion of the rock magma that has been rendered schistose by pressure. In thin sections of all specimens in which the schistosity is marked, the foliation is plainly seen to be due to pressure; for not only are the feldspars marked by many series of curved twinning lamellæ, but the rock is also shattered, and in the cracks separating its different portions a large quantity of new feldspar has been deposited.

Microscopic Description.—The texture as revealed by the study of thin sections is thoroughly granitic, in that none † of the components possess crystal outlines, though many of the eleolite grains and some of those of the albite have quite well defined rectangular cross-sections. With the exception of the rare zircon, the lepidomelane is the oldest constituent, but whether this is followed by eleolite or albite it is difficult to determine, since in most cases the eleolite and the larger grains of albite are separated by areas of finer grained feldspars that are certainly later in origin than either one of the two minerals mentioned. It is

* Ibid., p. 262.

† This statement applies only to the main mass of the rock, and is not true with regard to its acid or basic aggregations ("Schlieren"), where crystals of eleolite or of lepidomelane are not uncommon.

probable, however, that the eleolite preceded the plagioclase in its crystallization.

The only dark colored component visible is a dark green biotite,* present not only in the large plates already mentioned, but also as inclusions in the eleolite. In basal sections the mineral is so dark as to be almost opaque. In other sections the ray vibrating perpendicular to the cleavage is bright greenish-yellow, while that vibrating parallel to the cleavage is dark green. The absorption, therefore, is $\mathfrak{a} < \mathfrak{b} = \mathfrak{c}$. The apparently uniaxial, negative interference figure opens slightly when revolved under crossed nicols, and the extinction of the mineral is sometimes inclined to the cleavage about 1°. The composition, according to Clarke,† is that of a very basic lepidomelane:

SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	K_2O	Na_2O	H_2O	Total
32.35	17.47	24.22	13.11	1.02	0.89	0.70	6.40	4.67	= 100.83

In natural light the mass in which the lepidomelane is imbedded appears as a colorless matrix, for the most part transparent, but clouded here and there with opaque white and yellowish decomposition products of eleolite and the larger albites (figure 1, plate 7). Under crossed nicols this apparently homogeneous groundmass resolves itself into large dull grains of eleolite and albite, and a finely granular aggregate of brilliantly colored feldspars and cancrinite, and a few perfectly isotropic grains of sodalite.

The eleolite, although it sometimes has a rectangular cross-section, is usually in allotriomorphic grains, whose outlines are rendered more or less jagged by projections extending out into the areas between the surrounding grains. The inclusions that crowd it are glass and fluid cavities, the latter frequently containing movable bubbles, long narrow plates of lepidomelane, with their longer directions parallel to the vertical axes of their hosts, and various decomposition products, among which may be mentioned a few brightly polarizing fibers of some zeolitic mineral and an occasional flake of muscovite. Sodalite and cancrinite were also met with, in a single instance, as alteration products of the eleolite; but since they were not entirely inclosed by this mineral they can scarcely be spoken of as inclusions. Under crossed nicols many of the larger grains are discovered to be intergrown with a twinned feldspar, which,

*In spite of earnest search through sixteen sections of the Litchfield rock, no trace of any mica but this could be discovered although both Rosenbusch (Mikroskopische Physiographie, b. ii 1887, p. 85) and Clarke (Am. Jour Sci., 3d ser., vol. xxxiv, 1887, p. 134) mention the existence of two micas in it. In one section of the Cochnewagon rock the biotite is dark brown instead of dark green. It presents the pleochroism of ordinary biotite, and is certainly not a lepidomelane. The rock is much decomposed, and is different in so many of its features from the other specimens collected at this place, as well as at the localities in Litchfield and West Gardiner, that its consideration is entirely omitted from the present discussion.

†Am. Jour. Sci., 3d ser., vol. xxxiv, 1887, p. 133.

judging from the mass-analysis of the rock (page 241), must be albite. Many small areas of this inclosed feldspar occur with their axes in the same direction. Their material is not sharply defined from the surrounding eleolite, but appears to pass into it by insensible gradations.

Of the feldspars the most abundant is the cloudy albite occurring in the columnar crystals already mentioned. In the thin section these possess long quadrangular forms, characterized by a series of remarkably fine twinning lamellæ, whose close study affords the best evidences of the pressure to which the entire rockmass has been subjected. Individual twinning plates often wedge out and disappear, while others spring from the sides of cracks. Other lamellæ are bent and bowed, some are broken off sharply at cleavage cracks, while still others in the interior of the grains are crossed by a second series of striations running nearly at right angles to the first ones. There are also indications that some of these grains are composed of two feldspars, for their resemblance to Brögger's* pictures of cryptoperthite and microcline-microperthite is very striking. The character of the two feldspars, however, has not been certainly established, though it is quite probable that albite and microcline form one of the combinations. The specific gravity and composition of these albites have already been given (page 234). Since they contain but one per cent of K_2O it is quite clear that the potash molecule cannot play a very great rôle in the intergrowths.

The difficulty in determining the true nature of the constituent feldspars in these combinations is due principally to the fact that the large grains are penetrated in all directions by jagged embayments of a pellucid plagioclase with broader twinning lamellæ than those of the turbid phenocrysts and without inclusions of any kind. Small areas of this glassy feldspar occur all through the large albites, so that the latter appear to be completely saturated with the former. The saturating feldspar often has two sets of twinning striations. It polarizes in gray and blue tints, and always has ragged outlines when it does not grade into the enclosing albite. It seems impossible to assign any but a secondary origin to the included material. The large crystals are so corroded by it that in some cases but a slight film of the original substance separates the different areas of the new substance from each other. The different areas of the new feldspar, moreover, are optically continuous with one another, as are also different portions of the enclosing albite, so that the polarization of the intergrowths is very like that of quartz and orthoclase in micropegmatite.

Besides this saturating feldspar there are other feldspars occurring in small grains, in some instances forming a sort of mosaic in which all the

* W. C. Brögger: Zeits. f. Kryst., b. xvi, 1890, taf. xxii, fig. 3, and taf. xxiii, fig. 1.

other components of the rock lie, and sometimes filling what were apparently cracks in the rock mass (figure 2, plate 7). All these grains polarize with bright colors, and all are clear and perfectly transparent. They are all of about the same size, none ever have crystallographic outlines, and all are younger than the large crystals of albite that have been mentioned so frequently. In rare cases this mosaic itself is imbedded in a finer mosaic of the same character, except that it is saturated with cancrinite. The structure produced by the imbedding of the larger components of the rock in this fine grained mosaic is strongly suggestive of the mortar structure of Törnebohm, which is regarded by this author as a certain indication that the rock exhibiting it has been subjected to pressure and shearing.

Two feldspars are distinctly observable in the mosaic, and a third one may exist. The two undoubtedly present are so much alike in appearance that it is difficult in many instances to determine the nature of a particular grain. The number of untwinned grains however indicates the presence of an orthoclase, while the number of grains with straight narrow twinning lamellæ points to the existence of a plagioclase. Another feldspar almost surely present is microcline. It is in slightly larger pieces than the other two, and is well marked by the double twinning. It is impossible to speak more positively as to the nature of these feldspars, as cleavage cracks are not common, crystallographic outlines are never present, and the twinning lamellæ are bowed and bent to such an extent that readings of extinction angles are not decisive.

In separation by the Thoulet solution two lots of feldspar fell when the density of the liquid was 2.622 and 2.56 respectively. That which fell at 2.622 consists of grains usually striated in a single direction and of others in which no striations are noticeable. The latter extinguish at 19° from the cleavage, and show between crossed nicols the bar of an axial figure. Their analysis, made by Mr. W. H. Melville, of the United States Geological Survey, is that of a very pure albite (I):

	I.	Albite.	II.	Orthoclase.
SiO_2	68.28	68.62	65.14	64.6
Al_2O_3	19.62	19.56	18.19	18.5
FeO	.23	....	.25	....
CaO	.31	....	.33	....
MgO	.09	....	.16	....
K_2O	.39	....	14.14	16.9
Na_2O	10.81	11.82	1.68	....
H_2O	.09	....	.17	....
	99.82	100.00	100.06	100.00

The powder that fell at 2.56 contains some untwinned grains and many with the twinning striations of microcline. Its composition is given under column II. As will be seen by comparison with the figures for orthoclase, this mineral also is very pure. There can be no doubt that it is a potassium feldspar, and it is probable that it crystallizes in both monoclinic and triclinic forms.

In view of the fact that eleolite-syenite is defined as a rock consisting essentially of orthoclase and eleolite, it becomes of importance to determine whether the potash feldspars in the Maine rock are primary or secondary. It is very evident that they are younger than the eleolite and the large crystals of albite, and are of the same age as the albite grains in the mosaic. Their small grain, perfect transparency, lack of cleavage, and the method of their occurrence in narrow stringers and small areas between the undoubted primary constituents point to a secondary origin for all the minerals in the mosaic. The arrangement of these is, however, somewhat peculiar, in that in nearly every case they are more or less lenticular and their long axes are rudely parallel to the long directions of the areas which they form. This would indicate that the pressure by which the rock was made schistose acted after the feldspar grains of the mosaic were formed. The explanation of the phenomenon seems to be that the rock which originally consisted of eleolite, albite, lepidomelane, and perhaps some orthoclase or other feldspar, was subjected to great pressure attended by motion, that it was broken and shattered, and that the fragments were rolled upon one another, and at the same time albite and orthoclase were deposited in all the crevices as they were formed. The pressure and motion continued until all the newly formed grains became oriented, and some had developed in them twinning lamellæ. From all the evidence at hand it would appear that the microcline in the Litchfield rock is merely an orthoclase with secondary cross-twinning.

An indication of the correctness of this view is the fact that where the feldspathic mosaic is absent the rock is massive and not schistose—*i. e.*, where pressure has not produced foliation there is an absence of the small grains of feldspar composing the mosaic.

The only two constituents remaining to be described are cancrinite and sodalite. The latter may usually be recognized by its light blue color in natural light, though at times its tint is so pale that it can be detected only by the contrast afforded by the colorless minerals associated with it, which appear to be slightly tinged with yellow. Under crossed nicols it is perfectly isotropic. No idiomorphic forms occur, but the substance extends irregularly around the other components including them, as augite does the feldspar in many diabases. The most abun-

dant of the minerals imbedded in the sodalite are irregular grains of plagioclase, little plates of lepidomelane and cancrinite, and a few small flakes of a brightly polarizing micaceous substance. Eleolite is often intergrown with the sodalite in such a way that a large number of apparently isolated areas of the former polarize together. The relation of the sodalite to the other constituents leaves no doubt as to its age with respect to these. It is certainly younger than any of them. Therefore, since it is younger than components that are themselves younger than the eleolite, and at the same time is intergrown with the latter mineral, as described above, it must be an alteration product of this. The beautiful pieces that have been sent to the museums as mineral specimens are certainly secondary, for in them the sodalite is found on the faces of joint-cracks, and in most cases it extends back from these surfaces into masses of eleolite that lie near them.

The composition of compact masses of sodalite taken from seams in the Maine rock was found by Clarke * to be:

SiO_2	Al_2O_3	Na_2O	K_2O	Cl	H_2O		Total — (O = Cl)
37.33	31.87	24.56	0.10	6.83	1.07	=	100.22

The white alteration product of sodalite described by Dr. Clarke † under the name of hydro-nephelite was not seen in any of the sections examined. This is probably owing to the fact that the sections were all made from pieces of the rock taken from the interior of blocks at some distance from seams or joint cracks. Its microscopical description is so well given by Diller ‡ and Brögger,§ however, that little could be added to it by study of material in the writer's possession.

The cancrinite is not distinguishable from feldspar in ordinary light, except in thick sections, where it possesses a slightly yellowish tinge. In thinner sections it is colorless, transparent and without inclusions, other than pores containing liquid inclosing movable bubbles. Of these there are two kinds, viz, a series of long quadrangular and spindle-shaped cavities arranged in lines with their long directions parallel to the vertical axes of the cancrinite grains, and round and irregularly shaped ones running in lines that are usually sharply inclined (often perpendicular) to these axes. Under crossed nicols the mineral polarizes with very brilliant colors, and extinguishes parallel to the two well marked cleavages that traverse it. The grains, which are all allotriomorphic and elongated in the direction of the lateral axes, are found intermingled with the feldspar of the mosaic and in larger pieces scattered between

* Am. Jour. Sci., 3rd ser., vol. xxxi, 1886, p. 264.
† Ibid., p. 265.
‡ Ibid., p. 266.
§ Zeits. d. Kryst., b. xvi, 1890, pp. 234 and 636.

the eleolites and the larger albites. Dr. Clarke,* arguing from the result of his analysis of the mineral, declares that most of the cancrinite of the Litchfield rock is an alteration product of eleolite; while Rosenbusch,† on the other hand, cites it as an especially fine example of primary cancrinite. The microscope shows conclusively that some of the cancrinite has resulted from the alteration of eleolite. The most of it, however, is so far removed from eleolite that its relation to this mineral has not been discovered. It occurs principally in the mosaic, which has been thought to be of secondary origin, and is the youngest of its constituents, with the exception of sodalite. It has certainly crystallized from the magma that yielded the other minerals of the mosaic, and in this sense is original, but its chemical components may nevertheless have come from some of the eleolite that was destroyed at the time of the formation of the mosaic.

The composition of the commonest type of the cancrinite, the bright yellow granular variety, is as follows:

SiO_2	Al_2O_3	Mn_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	H_2O	CO_2	Total
37.22	28.32	tr.	tr.	4.40	19.43	0.18	0.07	3.86	6.22	= 99.70

Discussion and Summary.—A noticeable fact in connection with this rock is the absence of sphene, hornblende and augite. The former is present in nearly all normal eleolite-syenites, with the exception of those from Kangerdluarsuk in Greenland and from Fünfkirchen in Hungary,‡ while one of the last two is usually found, even though biotite be the most prominent of the bisilicates present. Another fact of interest in connection with the Maine rock is the great preponderance of albite among the feldspars. An analysis of the most common phase of the rock by Mr. L. G. Eakins gave:

SiO_2	= 60.39
Al_2O_3	= 22.51
Fe_2O_3	= .42
FeO	= 2.26
MnO	= .08
CaO	= .32
MgO	= .13
K_2O	= 4.77
Na_2O	= 8.44
H_2O	= .57
CO_2	= tr.
Total	99.95

* Am. Jour. Sci., 3d ser., vol. xxxi, 1886, p. 263.
† Mikroskopische Physiographie, ii, 1887, p. 86.
‡ Ibid., p. 87.

From this we calculate that the ingredients are intermingled in the proportions shown below:

	Rock.	Lepidomelane.	Cancrinite.	Eleolite.	Orthoclase.	Albite.	Aggregate.	Differences.
SiO_2	60.39	2.264	.744	7.436	17.588	32.091	60.123	.267
Al_2O_3	22.57	1.223	.566	5.862	4.911	9.221	21.783	.787
Fe_2O_3	.42 } 2.63							
FeO	2.26 }	2.444	. . . . . .	. . . . . .	.067	.108	2.619	.014
MnO	.08	.071	. . . . . .	. . . . . .	. . . . . .	. . . . . .	.071	.009
CaO	.32	.063	.088	. . . . . .	.089	.146	.386	—.066
MgO	.13	. . . . . .	. . . . . .	. . . . . .	.043	.040	.083	.047
K_2O	4.77	.049	.004	.773	3.818	.194	4.838	—.068
Na_2O	8.44	.448	.388	2.825	.454	5.080	9.195	—.655
H_2O	.57	.324	.077	.146	.044	.040	.631	—.061
CO_2	tr.	. . . . . .	.124	. . . . . .	. . . . . .	. . . . . .	.124	—.124
	99.95	6.886	1.991	17.042	27.014	46.920	99.853	
		.170 (= O)						
		7.056						

viz: 7 per cent of lepidomelane, 2 per cent of cancrinite, 17 per cent of eleolite, 27 per cent of orthoclase (and microcline), and 47 per cent of albite. As was indicated by the microscopic study, no plagioclase other than albite is present, and this, as is seen, is largely in excess of the orthoclase.

The rock, then, while certainly to be classed with the eleolite-syenites, is nevertheless very unlike those that have been described from other localities. It consists essentially of lepidomelane, eleolite and albite among its undoubted primary components, and of orthoclase, albite, cancrinite and sodalite among those of probable secondary origin. Even though the orthoclase should be regarded as primary, it is not in sufficient quantity to affect to any considerable degree the character of the rock. Its structure is seen to be thoroughly granitic where the deformation produced by pressure is not so great as to obscure all traces of its original character. Although, according to Rosenbusch's scheme, its composition would carry the rock among the theralites, its characteristics certainly point to the eleolite-syenites as its nearest relatives. The sodalite and cancrinite of the eleolite-syenites are abundant in the Maine rock and the dark color that is to be expected in the more basic plagioclase-eleolite rock is lacking. The plagioclase of the former is the most acid one known,

while the more basic members of this group of minerals are entirely wanting. Consequently, in spite of the great predominance of albite over orthoclase, we are quite justified in calling our rock an eleolite-syenite. Its large percentage of albite, however, and its possession of but one bisilicate constituent, and that a biotite (lepidomelane), seem to distinguish it as a very well defined variety of eleolite-syenite, as well characterized in the hand-specimen as in the thin section. Its peculiarities are so strongly marked that the rock seems worthy of a distinctive varietal name, for which no more appropriate one can be found than *litchfieldite*, derived from the familiar locality—Litchfield—whence nearly all the specimens in the museums were obtained.

Hawes' Hornblende-Syenite from Red Hill, Moultonboro, New Hampshire.

Historical.—The New Hampshire rock was described by Hawes as a hornblende-syenite in these words:

> "A beautiful variety comes from Red hill, in Moultonborough. It is composed essentially of orthoclase, which exists in thin tabular twinned crystals, which mostly lie in one plane, and consequently give to little specimens of the rock a stratified appearance. The hornblende, which is irregularly distributed, is black, but in thin sections it is deep yellow, and it incloses more or less biotite in its mass. Microscopic grains of blood-red hematite and black magnetite and crystals of apatite are detected, and by the aid of polarized light some plagioclase is found to be present. Only a very little quartz is seen in some little angular corners made by the melting of the straight edges of the orthoclase crystals. Little, partially crystallized grains of sphene are found, and some of the grains of hornblende are shown by polarized light to consist of two parts in twin relationship. As there are large accumulations of this rock, it is one of considerable importance."

Nothing is said of the method of occurrence of the rock, though similar ones are described as existing in dikes.

Mr. J. S. Diller, in his search for a typical syenite for the educational series of the United States Geological Survey, examined specimens of the Red hill rock sent him by Professor W. O. Crosby, of the Massachusetts Institute of Technology, who obtained them in turn from a man who was instructed to collect the material from Hawes' original ledges. A few minutes' survey of the specimens revealed the presence of blue sodalite, and a tiny piece treated with hydrochloric acid gelatinized easily. Sections of the rock were then made and turned over to the writer for investigation, the results of which are recorded in the present article. That the material furnished by Professor Crosby represents Hawes' rock is shown by its comparison with a specimen in the National Museum labeled in Hawes' own handwriting.

Occurrence.—As indicated in the title, the rock studied occurs at Red hill, just north of Center harbor, in the town of Moultonboro, Carroll county, New Hampshire. No definite information is available as to the amount of the rock found in this place, but from published descriptions of Red hill it seems likely that the entire eminence is composed of it; for we read in the "History and Description of New England"* that "towering up some 2,000 feet above the level of the sea is Red hill, formed of a beautiful syenite, in which the feldspar is of a gray-ash color."

Macroscopic Description.—So few specimens of the rock have been seen that it will be impossible to describe the characteristics of its mass as a whole. We shall have to content ourselves with a rapid survey of the specimens at hand, and with a sufficiently detailed study of their thin sections to prove conclusively that the rock is not a hornblende-syenite as supposed by Hawes, but is an eleolite-syenite as surmised by Diller. The six slides examined as representing the three types of the rock thus far obtained are, however, so nearly alike in their essential peculiarities that they may evidently be regarded as illustrative of the principal features of the occurrence.

The specimens furnished by Professor Crosby approach nearer in appearance to some varieties of the Arkansas eleolite-syenites than to any rocks with which the writer is acquainted. They are moderately coarse grained, pinkish-gray crystalline masses, containing irregular patches of an easily cleavable, lustrous, jet black mineral that sometimes measure a quarter of an inch in diameter and sometimes are microscopic in dimensions. In the pinkish-gray portion large even surfaces of a twinned feldspar are easily discernible. These are cross-sections of columnar or tabular crystals, and are the special features of the rock that are most prominent. Besides these are scattered here and there dull, irregular masses of eleolite, and occasionally tiny blue areas of sodalite. Neither sodalite nor eleolite is so common as in the litchfieldite, while cancrinite has not been detected in any specimens of the New Hampshire rock.

The piece in the National Museum corresponds more nearly to Hawes' original description than do the specimens collected more recently. A fragment of it shows a well defined banding, which is due to the flattening of the feldspars and the dark constituents and their arrangement in planes parallel to each other. From the bending of the flat feldspar plates and the existence of many small fractures crossing them at right angles to their long dimensions it would seem that the platy structure is the result of pressure without much attendant motion. The single thin section examined, however, affords no support to this supposition.

A third variety of the rock has recently been collected by Mr. M. M.

* Coolidge and Mansfield: History and Description of New England, vol. 1, 1859, p. 585.

Smith, who has kindly furnished to the writer all the material desired. In a letter accompanying the specimens Mr. Smith says:

"The rock I obtained on the northeastern side of Red hill, on land belonging to Mr. W. H. Mason. The ledge lies in the pasture on the southwestern side of the road."

In this variety the structure is more nearly granular than in the case of either of the others, and the rock is much fresher. The large twinned feldspars that are so characteristic of the first two varieties described are lacking in this. The groundmass of the hand-specimen is of a grayish-white color and is composed of brilliantly glistening facets of an untwinned feldspar and small dull gray areas of eleolite. Occasionally tiny Carlsbad twins of orthoclase may be detected, but these are rare. In this groundmass are large columnar crystals of a feldspar like that of the smaller grains, and large black grains of hornblende, frequently with idiomorphic outlines. The resemblance of this rock to a typical hornblende-syenite is so close that there need be no surprise that it was called such by so careful an observer as Hawes. The eleolite is not recognizable in the hand-specimen until after its presence has been ascertained by microscopical and chemical tests.

Microscopic Description and Discussion of Chemical Analyses.—A single glance at its thin sections shows the Red hill rock to be quite different in structure as well as in composition from the Maine eleolite-syenite. Its components are a light-colored augite, bright green and dark brownish-green hornblende, brown biotite, feldspar, eleolite and sodalite as essentials, and magnetite, sphene, apatite and leucoxene as accessories. The oldest of these are magnetite, apatite and sphene. The former is in little irregular grains and accumulations of grains, and the sphene is in rounded and irregular masses and in double wedge-shaped crystals, with the usual color and pleochroism of this mineral. The apatite is present in the familiar colorless prisms so well known. All occur as inclusions in all the other constituents, but they are more frequently in and around the aggregates of the bisilicates than elsewhere.

Next in age follow the iron compounds. These, as has been stated, are augite, hornblende and biotite, which, together with apatite, magnetite and leucoxene, form aggregates or accumulations, the primary constituents of which separated from the magma some time before the elements of the light-colored groundmass in which they are imbedded.

But little of the augite remains in the rock. That which is present exists as very light green, almost colorless cores, whose peripheries are fringed with bright green hornblende. The maximum extinction observed in these cores is 37°. In all cases the augite lies imbedded in an irregular aggregate of the green hornblende, biotite and leucoxene, of which the

first and last mentioned minerals are no doubt alteration products of the augite. The bright green hornblende is strongly pleochroic in bright green tints in sections parallel to the vertical axis and in green and brownish-green tints in basal sections. The cross-cleavage of hornblende is very apparent in the latter, and sometimes this is accompanied by the rectangular cleavage of augite. The inclusions of this hornblende, as of the augite from which it is derived, are apatite and small grains of magnetite.

Intermingled with the green hornblende and including large masses of it are large and small plates of biotite, whose strong pleochroism is in very dark brown and bright yellow colors. Its extinction, determined by means of the quartz ocular, is parallel to the cleavage, but its axial figure opens slightly when revolved between crossed nicols. There is no evidence that the mineral is an alteration product of augite. Its rela' to the green hornblende and leucoxene which it inclosed declares it to younger than these, or, more properly speaking, than the augite fro which these are derived. In addition to the green hornblende and the leucoxene,* the biotite also includes crystals of apatite and sphene that are probably original separations from the magma.

Another form of the biotite is surrounded by green hornblende in such a way that we must suppose a small quantity of the latter to have resulted from the alteration of the former, for the borders of the mica, like those of the augite, are fringed with a narrow rim of the hornblende.

Of the nature of the brownish-green hornblende but little has been learned. It is frequently in idiomorphic grains, bounded by the usual forms found on hornblende, and is often twinned according to the ordinary law. Its color in prismatic sections is dark green, with a slight tinge of yellow in a direction highly inclined to the cleavage, and dark brown, almost opaque in directions nearly parallel to it. In basal sections the ray parallel to $\mathfrak{a}$ is dark green, while that parallel to $\mathfrak{b}$ is almost completely absorbed. The scheme for the absorption is consequently $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. The extinction is high, certainly above 24°, and the inclusions imbedded in the mineral are those common to the other bisilicates. Around its edges are sometimes discoverable little masses of iron oxides that may indicate magmatic resorption. This variety of hornblende was seen in its greatest perfection in the slide made from Hawes' original specimen. Here it occurs not only in the aggregated basic concretions, but also in isolated idiomorphic grains, commonly associated with eleolite or its decomposition products. It is also abundant in the specimens obtained by Mr. Smith. From the fact that the mineral occurs so frequently in isolated

*The distinction here made between the two titanium minerals is merely one of origin, the granular secondary substance being called leucoxene, and the crystallized original titanate being denominated sphene.

idiomorphic grains, having traces of having undergone resorption, we must conclude that, like the augite and the biotite, it is primary in origin and not secondary, as is the bright green hornblende.

The colorless components forming the mass in which the dark aggregates lie are sodalite, eleolite and feldspar, whose relative ages are probably in the order named. The first two mentioned are in small quantity as compared with the feldspar, though the eleolite is in sufficient abundance to characterize the rock as an eleolite-syenite. When unaltered it is perfectly colorless. It occurs occasionally in prismatic* forms between the feldspar, but more frequently as irregular masses associated with the basic constituents of the rock and often surrounding them, and also as grains included in the intergrowths of albite and orthoclase. The time of its formation consequently was between that of the bisilicates and that of the feldspar. The inclusions in the eleolite, besides the sphene and bisilicates already mentioned, are flakes of a brightly polarizing, fibrous substance, and tiny grains of calcite. Both of these are decomposition products of their host, for as they increase in quantity the eleolite surrounding them gradually loses its transparency and other characteristics until finally it passes into a cloudy mass, consisting largely of a felt of the brightly polarizing fibers, studded here and there with grains of calcite.

The sodalite is distinguishable from the fresh eleolite only in polarized light, where it remains dark during an entire revolution. It occurs under conditions that are exactly similar to those under which eleolite exists. It is found cementing the bisilicates in the basic aggregates, and is often present as inclusions in the feldspar. Rarely is it discovered in pieces of any size between grains of feldspar. Perhaps its most characteristic form of occurrence is as inclusions in the feldspar. These are usually very irregular in shape, but occasionally the grains show very clearly the traces of dodecahedral planes (figure 2). That the isotropic grains are sodalite and not some other regularly crystallizing mineral may be beautifully shown by Lemberg's test,† in which a dilute acid solution of silver nitrate is allowed to come in contact with the uncovered section. In a portion of a slide treated in this way the isotropic grains were covered with a white coating of silver chloride, while the nepheline grains remained unaffected.

The sodalite, like the eleolite, is older than the feldspars, but is younger than the bisilicates. A single observation upon the relative ages of the first two mentioned minerals indicates that the sodalite preceded the eleolite in the time of its formation.

* It is probably this that was taken by Hawes for quartz (see description, p. 243).
† J. Lemberg: Zeits. d. d. geol. Gesell., b. xlii, 1890, p. 738.

The feldspar was the latest of all the components to crystallize. It constitutes about 80 per cent of the entire rock, and occurs almost exclusively in large Carlsbad twins, with irregular outlines. In spite of the abun-

FIGURE 2.—*Occurrence of Nepheline and Sodalite in Feldspar.*
1 = Nepheline ; 2 = Sodalite.

dance of apparent crystals in the hand-specimen, the thin section contains no grains with idiomorphic forms. All have such shapes as are permitted them by surrounding grains ; so that we have in this feldspathic portion

FIGURE 3.—*Eleolite Syenite from Red Hill.*

The slide shows a portion of a basic accumulation consisting of biotite, hornblende, augite (rectangular cleavage), sphene (stippled), and magnetite.

of the rock an interpenetrating mass of large twinned grains, which have, however, a well marked extension in a single direction, and thus a

columnar habit. In natural light the substance of the feldspar appears to be homogeneous, but under crossed nicols it is seen to be an intergrowth of two very different substances with extinctions corresponding to orthoclase and albite. The orthoclase has suffered the effects of alteration to a much greater extent than has the albite, and in consequence has often entirely disappeared, while its place is now occupied by a cloudy aggregate of kaolin or of micaceous minerals. The albite remains quite fresh, and so includes these secondary products. The other inclusions of the albite, as well as those of the orthoclase, are the eleolite and sodalite grains already referred to, with crystals of sphene, apatite, and dark green hornblende, and an occasional rounded grain of zircon; besides, of course, the usual liquid inclusions. It is not certainly known whether other feldspars than those mentioned are present or not, but it is assured by the analysis of the rock that if they do occur it is in but very small quantity. A separation of the feldspar from the powdered rock by a heavy solution points to the same conclusion; for while a great lot of material fell when the density of the solution was between 2.571 and 2.586, but a trifling quantity was precipitated on either side of these limits. An analysis of that portion of the powder whose specific gravity was 2.57–2.58 showed it to consist partly of eleolite and partly of feldspar. These were separated by extraction with hydrochloric acid and digestion with sodium carbonate, and then analyzed by Mr. W. F. Hillebrand, who reports these figures:

	Nepheline.	Feldspars.
SiO_2	45.31	66.85
Al_2O_3	32.67	19.50
Fe_2O_3	....	.13
CaO	2.00	.11
BaO	....	.07
MgO	.16	tr.
K_2O	5.70	5.80
Na_2O	12.60	7.44
H_2O	1.56 (calc.)	.31
Total	100.00	100.21

From the result of this analysis it is quite plain that the insoluble portion of the powder is a mixture of orthoclase and albite molecules; and since the microscope shows the presence of two feldspars in each grain, it is equally certain that these molecules are in the form of intergrowths of orthoclase and albite and not in their combination anorthoclase.

An analysis of the rock made by the same chemist gave:

SiO_2	59.01
TiO_2	.81
Al_2O_3	18.18
Fe_2O_3	1.63
FeO	3.65
MnO	.03
CaO	2.40
SrO	tr.
BaO	.08
MgO	1.05
K_2O	5.34
Na_2O	7.03
ZrO	tr.
H_2O (at 100°)	.15
H_2O (above 100°)	.50
P_2O_5	tr.
Cl	.12
Total	99.98

A single glance at this column affirms the statement above made that if any plagioclase other than albite is present in the rock it must be in very small quantity, for the 2.40 per cent of CaO indicated by the analysis is not more than enough to satisfy the demands of the 15 per cent of augite, hornblende, biotite and sphene that are known to exist there. Again, the percentage of K_2O is less than that of Na_2O. Even after allowing for the excess of Na_2O over K_2O in the eleolite and the presence of sodium in the sodalite, there still would remain a larger proportion of Na_2O than of K_2O. This would necessarily imply that albite is in excess over orthoclase.

Summary.—Although but few specimens of the Red hill, New Hampshire, rock have been examined, enough is known of the occurrence to enable us to declare it to be an acid eleolite-syenite, containing a larger proportion of albite than of orthoclase. Its essential constituents in the order of their ages are augite, hornblende, biotite, sodalite, eleolite and the two feldspars, orthoclase and albite. Its accessory primary components are apatite, crystallized sphene, magnetite and occasionally zircon, and its secondary constituents granular sphene and bright-green hornblende, besides fibrous decomposition products of eleolite and of orthoclase. It differs from litchfieldite in being less acid, in containing a little less albite and more undoubtedly original orthoclase, and especially in the possession of augite, hornblende and sphene, all of which are important elements in the composition of most eleolite-syenites. Besides, the New

Hampshire rock contains original sodalite, while this mineral in the Maine rock is principally secondary. The former therefore is more nearly a normal eleolite-syenite than is the latter, although it possesses an abnormally high percentage of albite, as indicated by the high percentage of silica and the low percentage of alumina, together with an excess of soda over potash.

Explanation of Plate 7.

Figure 1.—Litchfieldite in natural light. The dark mineral is lepidomelane. The large gray areas in the lower left of the picture and the light areas surrounded by the mica are eleolite. Everything else is albite. × .33.

Figure 2.—Litchfieldite under crossed nicols. Here the eleolite is easily distinguished from the plagioclase, since the former polarizes with a uniformly dark gray tint. Nearly all of the material included between plates of the lepidomelane are thus seen to be this mineral. The very light colored aggregate in figure 1 breaks up, under crossed nicols, into a mosaic of small plagioclase grains, that surrounds the basic elements of the rock and separates them from each other. × .33.

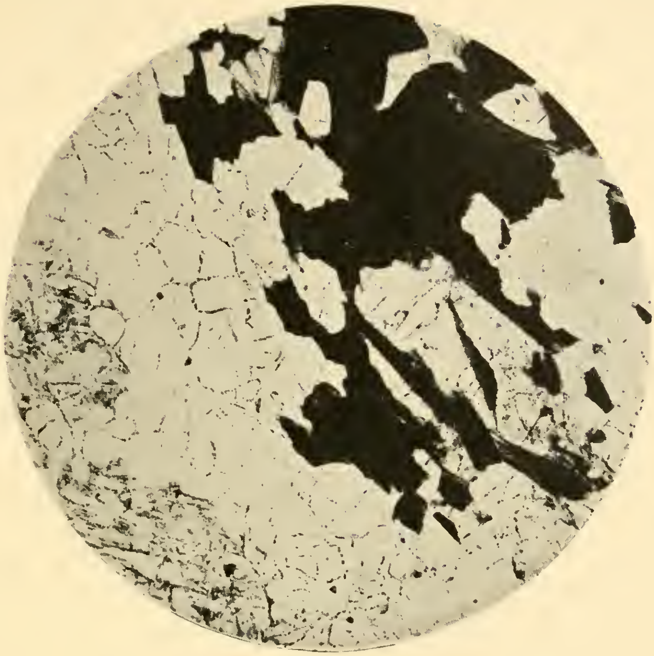


FIGURE 1—LITCHFIELDITE, NATURAL LIGHT.

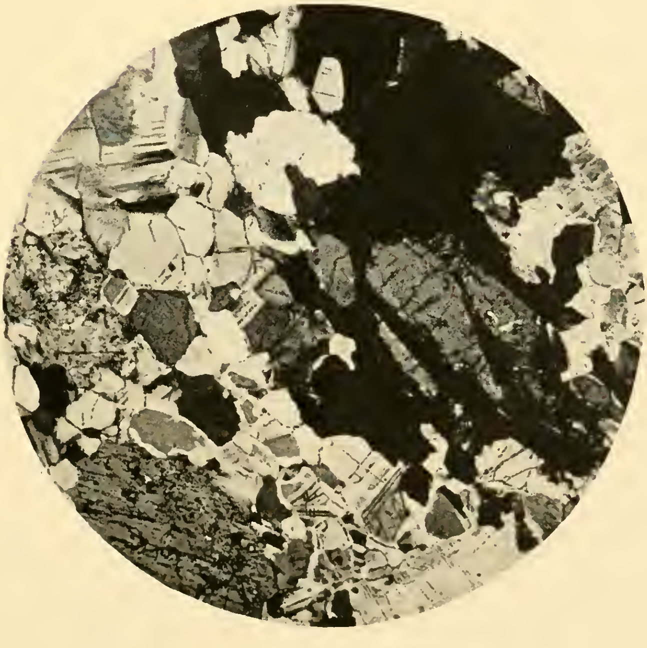


FIGURE 2—LITCHFIELDITE; CROSSED NICOLS.

MICROSTRUCTURE OF LITCHFIELDITE.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 253-282, PL. 8

A REVISION AND MONOGRAPH OF THE GENUS *CHONOPHYLLUM*

BY

WILL H. SHERZER

ROCHESTER
PUBLISHED BY THE SOCIETY
MAY, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 253-282, PL. 8 MAY 24, 1892

A REVISION AND MONOGRAPH OF THE GENUS *CHONOPHYLLUM*.

BY WILL H. SHERZER.

(Read before the Society December 30, 1891.)

CONTENTS.

Introductory.

This paper will aim to do for one genus of Paleozoic corals what is much needed for many others: it will attempt to give definiteness to the set of characters by which the genus may be recognized, will examine the various species assigned to it with reference to these characters, and will indicate the special points of structure by which it may be distinguished from its nearest relatives.

The work was begun upon the suggestion and under the direction of the late lamented Dr. Alexander Winchell, with the freedom of his valuable paleontological library.

Historical and Descriptive.

In the first volume of his great work, published in 1826, the learned Goldfuss described and figured a simple decorticated coral from Kentucky as *Cyathophyllum plicatum*.* The septa are stated to be somewhat thickened, not converging regularly at the center, but folded and twisted. A few pages later, but in the same list of new species of the genus *Cyathophyllum*, he described an essentially different coral from Sweden and inadvertently assigned to it the same name, *Cyathophyllum plicatum*.† Perceiving his error, the name of the latter form was subsequently changed to *C. perfoliatum* on the manuscript in the museum of the university of Bonn.‡

This Swedish coral was thus originally described:

> "Top-shaped, simple and free. The cells proliferating from the center are funnel-shaped and thin, show a radiate, regular folding instead of radial lamellæ, and are partly free at their edges, partly grown together in layers. This coral shows most clearly the cell structure of this genus."

The excellent figure given shows the coral to differ very essentially from *Cyathophyllum* as at present characterized.

In 1831 Ehrenberg presented a paper to the Berlin Akademie der Wissenschaften, in which he refers *Cyathophyllum plicatum*, *C. ceratites*, *C. flexuosum*, *C. vermiculare*, *C. secundum*, *C. lamellosum* and *C. placentiforme*, all of Goldfuss, to *Strombodes* of Schweigger.§ Aside from the fact that

* Petrefacta Germaniæ, erster theil, 1826; page 54, tab. xv, fig. 12.

† Page 59, tab. xviii, fig. 5.

‡ Monographie des Polypiers Fossiles des Terrains Palæozoïques 1851, Edwards and Haime, page 405; Histoire Naturelle des Coralliaires, Milne-Edwards, tome troisième, 1860, p. 399.

§ Beiträge zur physiologischen Kenntniss der Corallenthiere im allgemeinen, und besonders des rothen Meeres, nebst einem Versuche zur physiologischen Systematik derselben: Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin, 1832 (1834).

the structure of the Kentucky form only would permit its reference to this genus, there is no doubt that this is the *plicatum* meant when it is noted that the enumeration of these species by Ehrenberg follows the order of description by Goldfuss. Had the reference been to the Swedish coral it would have stood last in the list. Lonsdale, however, some eight years later, in describing corals from the Wenlock limestone of England, made this latter form synonymous with *Strombodes plicatum* of Ehrenberg.* The following description and the figures which accompany it render it almost certain that he really had in mind the structure of the Kentucky coral, the *plicatum* proper and not the *perfoliatum*:

"This coral is essentially distinguished from *Cyathophyllum* and *Cystiphyllum* by internal structure, the center consisting not of transverse plates, resembling the septa of a *Nautilus*, or of bladder-like cells, but of lamellæ contorted spirally. In the description of *Strombodes* by Schweigger and other authors, this structure is not mentioned; it is presumed, nevertheless, that the fossil here represented is a *Strombodes*, and that it is the *S. plicatum* of Goldfuss."

It seems very probable that figures 4*b* and 4*c* are of *Ptychophyllum patellatum*, Schlotheim, sp.,† while the affinities of the other forms are more uncertain and indeterminate from the figures and description.

In his "Silurian Fossils of Ireland"‡ McCoy refers certain forms, "Rare in the green slates of Doonquin, Dingle, county Kerry," to the Swedish coral under the name *Strombodes plicatus*, simply following the lead of Lonsdale.§ Under the name *Cyathophyllum plicatum*, Goldf., de Koninck described and figured a series of specimens from the Carboniferous of Belgium,‖ comparing them with the original Kentucky coral of Goldfuss in the Bonn museum. This type and the forms associated with it have no interest in this connection further than their complete separation from the Swedish *perfoliatum*. Milne-Edwards thought that the Kentucky coral might be referred to *Hallia*, E. and H.¶

In a work which I have been unable to consult (the second edition of Lamarck)** Milne-Edwards refers certain corals to the *C. plicatum* (*perfoliatum*) of Goldfuss; and with this possible exception there seems to have been no other specimens of this coral described or figured from 1826 to 1850. Recognizing that this form has no relationship with *Cyathophyllum*, Edwards and Haime, in their "British Fossil Corals,"

* Murchison's Silurian System, pt. ii, 1839, pp. 691–692, pl. 16 *bis*. figs. 1, 4*a*, 1*b*, 4*c*.

† Hist. Nat. des Cor., 1860, vol. iii, p. 400; Monographie der Zoantharia Sclerodermata Rugosa (1873), Wladislaw Dybowski, p. 112.

‡ 1846, p. 61.

§ A Monograph of the British Fossil Corals, pt. v, p. 291.

‖ Description des Animaux Fossiles qui se trouvent dans le Terrain Carbonifère de Belgique, 1842–4, p. 22, pl. *c*, figs. 1*a*–*g*

¶ His. Nat. des Cor., vol. iii, p. 357.

** Vol. ii, 1836, p. 431.

founded upon it the genus *Chonophyllum*, and assigned to it the following generic characters :

"Corallum simple, and constituted principally by a series of infundibuliform *tabulæ*, superposed and invaginated, the surface of which presents numerous septal radii equally developed, and extending from the center to the circumference. No *columella* nor *walls*."*

The following year this same description reappeared in their "Polypiers Fossiles,"† with the additional note—"The chonophylla have some relationship with *Strombodes*, but they always remain simple and present no walls ; they differ from the ptychophylla by the absence of any central organ." This was then again published by Milne-Edwards in 1860.‡ Morris, in 1854, referred the genus to the then imperfectly known *Heliophyllum*, and this genus to *Strephodes* of McCoy,§ including under it the *Cyathophyllum perfoliatum* of Goldfuss and the *Strombodes plicatus* of Lonsdale. Pictet followed the description of the founders, simply omitting the statement in regard to the absence of wall.‖

The first American species was described by Billings in 1860,¶ but neither in connection with this description nor with another five years later does he offer any contribution to the generic literature. He was guided, in all probability, by the general resemblance between his types and the excellent figure of Goldfuss rather than by any of the generic descriptions or his own imperfect knowledge of his specimens. Dybowski, in his elaborate monograph on zoantharia rugosa, does not recognize the genus. Based upon a study of the first of Billings' species, *C. magnificum*, Dr. Rominger, in 1876, published the most complete and satisfactory diagnosis of the genus yet made :**

"Single turbinate polyparia, composed of invaginated, radially plicated cell cups, which are intimately united within the central area, and form with their linear plications continuous vertical crests, extending through the whole length of the corallum, and uniting in the center into a somewhat twisted fascicle, but without composing a solid central axis. The interlamellar interstices of this central fascicle or core are traversed by transverse vesiculose plates, but no larger transverse diaphragmatic septa are observable. In the peripheral area the structure is entirely different. The connection between the invaginated cups becomes more loose, the linear plications open themselves and spread horizontally, forming gradually widening and moderately convex band-like folds of the expanded laminar cup walls, which are superimposed in well-defined membraniform layers, one

* Brit. Foss. Cor., pt. i, 1850, p. lxix.

† 1851, p. 405.

‡ Hist. Nat. des Cor., 1860, vol. iii, p. 398.

§ Catalogue of British Fossils, 1854, pp. 49, 57, 64, 65.

‖ Traité de Paléontologie, vol. iv, 1857, p. 457.

¶ Canadian Journal, new series, vol. v, 1860, pp. 264–265.

** Geological Survey of Michigan, vol. iii, pt. ii, pp. 115–116.

reposing on the granulose prominences of the surface of another, and more intimately connecting in the linear furrows between the plications, which correspond to the interlamellar spaces of other zoantharia rugosa, but were confused by Billings with the lamellæ. * * *"

Zittel gives in his Handbuch* a brief description of *Chonophyllum* which agrees with that of Pictet. We have been unable to find any recognition of the genus in the publications of Professor H. A. Nicholson. Mr. S. A. Miller, in his "North American Geology and Paleontology,"† gives a new lease of life to the antiquated description of Edwards and Haime.

In 1852‡ Professor James Hall founded his genus *Conophyllum* ("*conus* and *folium*; in allusion to the inverted conical septa"), and described the single species *Conophyllum niagarense*. After describing their *Chonophyllum ellipticum* in 1873 Hall and Whitfield add: "This genus is apparently identical with *Chonophyllum*, Hall, *Paleontology of New York*, vol. 2, published in 1852, though actually in print more than two years earlier."§ Either from this note or from the nearly identical name, Hall's genus has been quite generally confused with that of Edwards and Haime. The species upon which it was founded will be shown presently to be a *Cystiphyllum*, so that it can in no sense be regarded as a synonym.

Confronted with this unsatisfactory condition of the generic literature, we begin our labors upon the genus.

Type Species.

The celebrated French paleontologists who founded the genus gave as the type "*Chonophyllum perfoliatum*; *Cyathophyllum perfoliatum*, Goldf., tab. xviii, fig. 5." This species, previously referred to, was founded upon a single specimen from the Upper Silurian (Niagara) of the island of Gotland, Sweden, and now deposited in the museum of Bonn university. The figure of Goldfuss shows that the septa, instead of being lamellar plates as in typical rugose corals, are formed by a series of superposed layers, convex upward, and curved downward at their edges to form the side faces of each septum. This structure is also shown, but less clearly, in a photograph kindly prepared for me by Professor Carl Schlüter, of Bonn university (see plate 8, figure 1). We regard it as one of the chief characteristics of the genus *Chonophyllum*. In a letter of May 10, 1890, Dr. Gustav Lindström, of Stockholm, writes that in his last cata-

* Handbuch der Palaeontologie, band i, 1880, p. 229.

† 1889, p. 177.

‡ Paleontology of New York, vol. ii, 1852, p. 111.

§ Twenty-third Report on the State Cabinet of New York for 1869, 1873, p. 233.

logue of Swedish fossils he referred certain rare forms from Gotland to this species of Goldfuss, but upon closer examination he finds them to differ; and he considers *Chonophyllum perfoliatum* to be identical with *Ptychophyllum patellatum*, Schloth., sp. The specimens described by Edwards and Haime he regards as quite different. Owing to the confusion thus occasioned, he thinks it would be wise to abandon the genus and distribute its species among other genera. Professor Schlüter made a personal examination of the specimen for me and came to the same conclusion in regard to its relationship. He reports it taller than an ordinary *Ptychophyllum patellatum* and its septa less twisted at the center, but in other respects similar. Reasons will be given presently for thinking that this cannot be a *Ptychophyllum*. In the meantime it seems hopeless to try to draw any generic characters from this specimen or from any of the early literature. If the Swedish coral and those of Edwards and Haime were all that were to be disposed of, this paper would not have been prepared. As it is, however, a well marked and interesting group of forms occurs, readily separated from typical forms of all other genera and apparently related to the original of Goldfuss. If this type coral is *not* generically related to these, or if it is referable to some previously established genus, then a new generic name must be proposed for this group. If, however, it *is* so related, then it can stand only nominally as the type, and the details of structure must be drawn from other sources. The horns of the dilemma presented us then are (1) to alter the name of forms familiar to American paleontologists for over a quarter of a century or (2) to draw the details of structure from the second acceptable species assigned to the genus and general characters only from the original specimen. We believe that we shall meet with the approval of most, if not all, working in this line if we grasp the latter alternative; and hence we have studied *C. magnificum*, Billings, in this way and around it have grouped the related species. This is one of the largest and most magnificent of our simple rugose corals, the first American species to be described, most widely distributed and abundant, and showing most typically all points of structure.

Generic Characters.

Growth.—The representatives of *Chonophyllum* must be classed under the monastrés of Fromentel, or organisms which increase entirely by ova rather than by gemmation or fission. In some specimens of *C. ponderosum*, Rom., however, there is found a central calicinal budding of from one to four corallites, leading to a loose variety of compound growth. The characteristic form is short conical, turbinate or patellate, but a conicocylindrical growth, with little or no curving, is not uncommon in some

species. The base may be acute or obtuse and provided with an attachment scar. The outer calicinal margins are, typically, horizontally expanded and at times more or less reflexed. The size varies with the age and species, in *C. magnificum* attaining a greater diameter than in any other known simple coral. Fragments have been found which belonged to specimens not less than 22 or 23 cm in diameter. The single specimen upon which this species was founded had a diameter of 16.5 cm and an estimated length of 11.5 cm.

Outer Covering.—Owing to the peculiar formation of the septa there is neither necessity nor opportunity for the formation of a true wall such as exists in typical rugose corals. A simple, protective, epithecal covering was secreted and deposited by the "randplatte," or that portion of the polyp projecting over the edge of the calyx. This covering conforms to all the regularities and irregularities of the corallum itself, shows the ordinary circular accretion ridges of growth, and is longitudinally striated with narrow grooves and broad flat or concave bands, gradually increasing in width from the base toward the edge of the calyx. These grooves mark the position of the interseptal cavities and the broad bands the position of the septa themselves. Thin sections show that the epitheca is in contact with the under concave surface of the septa only here and there, and that it receives its support mainly from the ridges produced by the downwardly deflected edges of the series of layers which form them. Owing to this loose connection with the body of the corallum the epitheca is, in many specimens, either partially or completely lost, perhaps from marine or atmospheric agencies. In consequence, decorticated forms are somewhat characteristic of the genus, and it was this fact which led the founders to assert the absence of wall rather than any real knowledge of the outer covering which they were able to obtain from their limited number of specimens. In all recognized species, radicinal and spinulose processes are absent.

Calyx.—The calyx is generally spacious and deep in comparison with the height of the corallum. In some forms, however, it may be shallow and basin-like; in others there is an abrupt and deep central pit, with nearly vertical sides and broadly expanded margins. The outer edges may be horizontally explanate or reflexed upon one or all sides. The fovea is entirely absent or it exists only in the most rudimentary condition. The bottom of the pit is in general flat, never smooth, but in one species (*C. ponderosum*) a distinct elevation may be formed by the twisting together of the primary septa.

Septa.—The original specimen of Goldfuss contains 76 septa; in *C. magnificum* they range from this number to 120 in mature specimens, while in *C. ponderosum* they may reach 140. In the specimens of Edwards

and Haime the septa are stated to be of equal length; but in all forms examined we have found them alternating, of two orders, those of the second order terminating as they reach the central pit, those of the first extending to the center. These primaries may remain straight or become more or less twisted, but not so as to form a columella. Viewed from the calyx the direction of the twist is left-handed, *i. e.*, contrary to the hands of a watch.

Near the base and along the central vertical axis the septa present the form of vertical lamellæ, apparently similar to the ordinary lamellar septa; but as they pass outward from the center and upward from the base to the outer calyx margin they gradually thicken until in some of the largest forms of *C. magnificum* they are 5 mm across at the periphery of the calyx. In the calyx about the pit the septa appear thin and sharp, but pass outward as gradually broadening convex bands, separated in the outer area by very narrow grooves which mark the position of the interseptal cavities. If the outer edges of these septa are examined in decorticated specimens, or if vertical sections are prepared through this outer area, each septum is seen to be made up of a series of delicate, regularly curved, superposed membraniform layers with their convexities upward (figure 2). It was these spaces which Billings mistook for the interseptal spaces* as first pointed out by Dr. Rominger.† The regularity, distance apart, and thickness of these layers are subject to some variation in the different species. They are most beautifully and typically developed in *C. magnificum*, where they average about 5 or 6 to the mm, but range from 3 to 12 to the mm. In this same species their average thickness in several thin sections was found to be about $\frac{1}{20}$ mm, the thickest being $\frac{1}{10}$ and the thinnest ones observed $\frac{1}{50}$ mm.

Along the medial plane of each septum these layers are approximately horizontal for a short distance, curve gradually downward toward the sides, and finally are sharply deflected, fusing with one another along their edges to form the side faces of the septum. Occasionally a layer, or a series of layers, unites directly with those just beneath before reaching the side, and thus takes no part, for some distance at least, in the actual formation of the septal faces. When the septum has become too narrow, an upper layer may send down its edges upon each side completely enwrapping as many as 12 or 15 older ones, thus suggesting their method of growth. In general, these layers are not continuous from one septum to its neighbor, but each septum is made up of an independent series. Occasionally they pass completely across for a short distance, arching upward in the interseptal cavity and assisting in the formation of the vesi-

*Can. Jour., new series, vol. v, 1860, p. 265.

†Geol. Surv. of Mich., vol. iii, 1876, pt. ii, p. 115.

cles. (Figure 2, plate 8, will be found on minute examination to show this structure.) These layers are drawn as continuous by Billings, not only from septum to septum but also through the center.* It is this erroneous conception of them which has caused the genus to be described as having complete tabulæ and as made up of superposed and invaginated cell-cups.

In radial sections through the septa the cut edges of these layers appear as delicate parallel lines, sloping gently from the edge of the calyx downward toward the center. Intersected at right angles by the supporting growths they present, in typical forms, a *Stromatopora*-like appearance (figure 5). As the septum approaches the center the layers become more sharply bent, the side faces are brought more closely together, and there is formed a thin but double septum not to be distinguished from those of ordinary corals.

As a support for these delicate layers there are abundantly developed upon the upper surface of each, granular or spinulose processes. In certain specimens of *C. magnificum* vertical plates are formed which may be somewhat curved or warped, presenting a vermiform appearance under the hand lens, and arranged across the septum (figure 3). These may be over a mm in breadth and continuous upward for several mm, actually intersecting the layers. They may start as simple spinules and gradually widen into plates as they ascend. In certain cases they are simply placed in corresponding, or nearly corresponding, position upon the successive layers. These growths have their flat faces shown in figure 2, their edges in figure 5, and their cross-sections in figure 3. On the side faces of the septa these growths are reduced to rounded granulations, and under this form extend inward to the pit (figure 5). They have been observed here to be at times crowded together into rows extending, for short distances, upward and outward. A rather characteristic roughened appearance is thus given to the septa when viewed from the calyx.

The forms which may be referred to the genus do not offer advantages for the determination of the order of the interpolation of new septa, owing to their general shape and structure. The widening of the septa at the edge of the calyx endeavors to keep pace with the diametral growth of the corallum, thus giving occasion and necessity for the introduction of few new ones. The septa generally start from the base with an irregular spiral twist in which the foundations are early laid for nearly all that will be needed. A young specimen of *C. magnificum* with a height of 12 mm and a calyx diameter of 23 mm has 72 septa, while a mature specimen of the same species, 80 mm in diameter, has but 86. Another specimen in expanding its calyx from 18 to 100 mm and

* Can. Jour., new series, vol. v, pl. i, figs. *a* and *c*.

growing vertically 40 mm has gained but *two* new septa. In some forms, however, a greater number of new ones are introduced showing the tetrameral structure and pinnate arrangement along the cardinal septum, apparently following the law of Dr. Kunth. Others are introduced irregularly, however, throughout the quadrants without regard for any established statutes.

Dissepiments.—A well developed vesicular structure occurs in the outer, narrow, interseptal cavities as first pointed out by Rominger. These vesicles are generally delicate and rendered more or less irregular by the introduction of larger ones, probably produced by the union of neighboring septal layers (figure 4). In general they are formed by narrow bands, united along their edges to opposite septal faces, convex upward and superposed in such a way as to cut off the greatest amount of space with the least expenditure of material. In this we have a clue to the use of these structures. As the growth of the polyp demanded more commodious quarters, a gradually expanding corallum was constructed. The lower, unoccupied portions, now entirely useless, had to be shut off from that which was habitable by ectodermal secretions of calcium carbonate. This was accomplished in three ways among the Paleozoic corals: (1) by vesicles alone, (2) by tabulæ alone, or (3) by a combination of vesicles and incomplete tabulæ. In the case of *Chonophyllum*, vesicles were deposited in the outer area and in the central area irregular transverse leaflets which represent rudimentary tabulæ. In the case of polyps which early matured and then continued to build a long cylindrical corallum, as in *Zaphrentis gigantea*, etc, there may be needed some such explanation as that given by Verrill.*

In the outer area these vesicles filled the interseptal cavities to within one or two mm of the surface of the septa, but about the pit they were left more open, allowing the thin septa to project with their granulated surfaces.

Central Area.—As has previously been stated, the primary septa reach the center as double lamellar plates, where they may be more or less twisted, but not so as to form a columella. Vertical sections through this region show the septa as angularly wavy, vertical lines. In the vicinity of the pit the vesicles become more irregular and elongated, and the plates forming them pass into irregular transverse leaflets. No true tabulæ are to be found in any of the species, although when these leaflets occur at approximately the same level in adjoining wedge-shaped cavities between the septa they, for short distances, may simulate irregular tabulæ. A patch of this central area is shown in the lower portion of figure 5 (plate 8); although small, it is entirely characteristic.

---

* Am. Journ. Sci., 3d series, vol. iii, 1872, p. 187.

CLASSIFICATION.

Edwards and Haime located the genus in their family *Cyathophyllidæ*, tribe *Cyathophyllinæ*, thus ascribing to it a regularly radiate septal apparatus, superposed tabulæ, and no true columella.* They made no provision in their classification for a coral in which the tabulæ are absent or rudimentary, with regularly radiate septa and vesicles well developed. In his very elaborate classification of the rugose corals Dybowski † does not include the genus, and no satisfactory disposition can be made of it either in his scheme or in the much simplified form of it adopted by Zittel. This latter author places the genus under *Diaphragmatophora*, Dyb., thus ascribing to it complete tabulæ with dissepiments wanting or rudimentary. ‡

The characters to be taken note of in its classification are a tetrameral, simple growth; regularly radiate septa formed by delicate, superposed layers, convex upward; a simple epithecal wall; well developed dissepiments; and absence of fovea, columella, and true tabulæ. These peculiarities of structure require that special provision be made for the genus in any classification adopted.

LIST OF SPECIES.

Results of defective Definition.—When we consider the vagueness which has characterized the genus *Chonophyllum* we are not surprised to find a wide range of structure in the species assigned to it. Tabulæ well developed, tabulæ absent; dissepiments occupying but a portion of the corallum, dissepiments filling the entire visceral cavity; septa remarkably developed; septa reduced to mere ridges or rows of spines. In the ten species thus far assigned to the genus there are at least five different genera represented, and of those who have described them, excepting possibly those who have worked conjointly upon a species, no two have had in mind the same set of generic characters. As the result of some correspondence with those who have worked furthest in this line, I have found them generally loth to express any opinion in regard to the distinguishing characteristics of the genus.

1. *Chonophyllum perfoliatum*, Goldfuss, sp.

Cyathophyllum plicatum, Goldf. Petref. Germ., erster theil, 1826, p. 59, tab. xviii, fig. 5.

Cyathophyllum perfoliatum, Goldf. MSS. in Bonn museum.

* Brit. Foss. Cor., 1850, pt. i, p. lxix.

† Mon. der Zoan. Scler. Rug., 1873, pp. 74–84.

‡ Handb. der Pal., vol. i, 1880, p. 229.

Cyathophyllum plicatum, Milne-Edwards. Sec. ed. of Lamarck, t. ii, 1836, p. 431.

Chonophyllum perfoliatum, Edwards and Haime. Pol. Foss. des Terr. Pal., 1851, pp. 405–'6.

" " Edwards and Haime. Brit. Foss. Cor., pt. iv, 1853, p. 235, tab. l, fig. 5.

" " Milne-Edwards. Hist. Nat. des Cor., vol. iii, 1860, p. 399.

The original description of this species has been quoted, and the opinions of Dr. Schlüter and Dr. Lindström have been cited. The Swedish coral has a turbinate growth, but is elongated by successive expansions and contractions of the calicinal margins. It has the central pit and horizontally expanded growth found in many forms of *Chonophyllum* (figure 1). No fovea is indicated. There are 76 septa, but slightly twisted at the center and showing in the photograph, under a magnifier, a coarse granular appearance. Each septum seems to be made up of curved, superposed layers just as in the forms described, although they are flatter than in *C. magnificum*. They are regularly convex upward and *not angular*. The general shape of the corallum, with the central pit and explanate margins, the absence of fovea, the slight twisting of the septa at the center, their granular appearance and their formation of convex, superposed layers—all taken together, render it more than probable that this coral is generically related to our *C. magnificum*. Goldfuss has certainly *figured* for us a *Chonophyllum*, whatever may be the true position of the coral itself.

There is nothing about the descriptions of this species by Edwards and Haime in any way suggestive of the structure assigned to it by Goldfuss—"a regular, radiate *folding* instead of radial lamellæ." Their descriptions would apply equally well to many species of very different genera. That given in their "British Fossil Corals" reads as follows:

"*Corallum* simple, straight, rather elongate. *Calice* not remarkably deep, and of a subconical form. *Septa* (60 to 74) equally developed, straight, and extending almost to the center of the corallum. Some vestiges of a rudimentary septal fossula are visible. Height about 3 inches, diameter about 2 inches. Found at Torquay. (Collection of Dr. Battersby.) A fossil found at Wenlock, and belonging to the collection of M. d'Archiac, appears to belong also to this species."

For any information concerning the actual structure of these forms we must rely upon the figure.* The specimen figured is imbedded in a mass of foreign material and shows an irregular longitudinal section near the center. It is about 8 cm in length by 5 cm in breadth, in general form

* Loc. cit., tab. l, fig. 5.

and shape of the calyx similar to the Swedish coral. The corallum is represented as made up of approximately parallel and wavy horizontal laminae, averaging about two to the mm. These were supposed to represent the complete tabulae. We know of no coral outside of the genus *Chonophyllum* proper which could present a longitudinal section similar to that shown in the lower two-thirds of this figure. We have prepared a corresponding section of *C. ponderosum* which is strikingly similar in general appearance. In this portion of the figure these layers are not continuous through the center as they appear in the upper third, but here are drawn the vertical edges of the central septa, under a lens showing the angularly wavy appearance described for *C. magnificum*. Supporting growths are represented throughout the section. We regard this specimen as belonging to the genus, probably to the same species as the Swedish coral, and cut so as to show the edges of the septal layers. The upper portion of the figure, however, it must be confessed, with these layers continuous across the central cavity, could not have been copied from a *Chonophyllum*. It may be to some extent ideal, as are the two figures of Billings previously referred to.

A later reference is made to the Wenlock specimen mentioned above:*

"It is not without some hesitation that we refer to this species, already described in the preceding chapter as being common in the Devonian formation, a coral found by M. d'Archiac in the Silurian rocks at Wenlock. The only apparent difference between this fossil and the Torquay specimen consists in the form of the calice, the border of which is not everted."

This specimen as figured † has a length and diameter of about 4 cm., is obtusely pointed and slightly curved. The calyx is basin-shaped without explanate margins, and shows no fovea. There is a well developed epitheca, giving here and there the appearance of coarse radiciform processes. The septa number about 100, and are apparently angular. The general form of the coral and its calyx, the well developed epitheca and radiciform processes, combined with the apparently angular or "roof-shaped" septa, convinces us that this is an *Omphyma*, found abundantly in the same locality, in which the foveae are obsolete, as frequently happens.

A specimen figured by Pictet as belonging to this species is slenderly cylindrical, the surface giving the appearance of invaginated, projecting cell-cups.‡ Its structure may conform to the description of Edwards and Haime, but it has no affinity with *Chonophyllum*.

A coral which is supposed to belong to this species was collected from the Devonian of the Eifel by Dr. Rominger, and is now deposited in the

* Loc. cit., pl. v, p. 291.

† Loc. cit., tab. lxviii, figs. 2 and 2*a*.

‡ Atlas to "Traité de Paléontologie," pl. 108, fig. 2.

museum of the university of Michigan. It has a height of 10 cm and a diameter at the broadest part of 7 cm. In its general structure and external appearance it suggests the specimen of Edwards and Haime. On closer study, however, it is found to possess all the essential characters of *Cyathophyllum helianthoides*, Goldf., some abnormal growths of which are figured from the same locality by Goldfuss.* The septa are lamellar, and are angular or "roof-shaped" in the outer area, polished sections showing the structure to be afterward described as peculiar to this form. Several buds have started in the outer area which show the characteristic reflexed growth and the compound tendency of the coral.

2. *Chonophyllum elongatum*, Edwards and Haime.

Chonophyllum elongatum, Edwards and Haime. Pol. Foss. des Terr. Pal., 1851, p. 406, pl. viii, figs. 1, 1*a*.
" " Milne-Edwards. Hist. Nat. des Cor., vol. iii, 1860, p. 399.

Under this name Edwards and Haime described a second species in 1851 as follows:

"Corallum elongated, cylindro-turbinate, straight or very feebly curved, presenting a great number of projecting swellings and interruptions in the continuity. Epitheca well developed; the exterior portions of the corallum subvesicular. Calyx moderately deep. 74 to 76 septa, very slender and equal. Height 7 to 8 cm; diameter of calyx, 2 to 3. Devonian, France; Nehou (Manche). Collection of Verneuil."

Their figure 1 shows a slender, cylindrical coral, apparently made up of a series of invaginated cell-cups, the irregularities of which give exteriorly a subvesicular, roughened appearance. 1*a* is a view of an enlarged calyx, showing the septa angular in the outer area, as is seen in *Omphyma* and *Ptychophyllum*. The general shape and structure of this specimen and the thin angular septa certainly remove it from the forms which we have grouped about *C. magnificum*. It was stated by the founders to differ from *C. perfoliatum* by its more elongated, slender form and more infundibuliform tabulæ.†

3. *Chonophyllum niagarense*, Hall, sp.

Conophyllum niagarense, Hall. Pal. of N. Y., vol. ii, 1852, pl. xxxii, figs. 4 *a–n*.
Cystiphyllum niagarense, Rominger. Geol. Surv. of Mich., vol. iii, pt. ii, 1876, p. 138, pl. xlix, fig. 3.

---

* Loc. cit., tab. xx.
† Brit. Foss. Cor., pt. iv, p. 235.

The genus *Conophyllum* was founded upon a group of corals from the lower Niagara of New York, described by Professor Hall as *Conophyllum niagarense.* For reasons already pointed out, these have been quite generally included under *Chonophyllum*, and Mr. S. A. Miller figures a specimen as illustrative of this genus.* After examining a series of specimens from New York, Michigan, Indiana, Kentucky and Iowa, we have no hesitancy in assigning them to *Cystiphyllum*, although the septa are at times more than ordinarily well developed. The specific description and the figures given by Hall leave no doubt as to the position of these forms:

"Irregularly cylindrical, elongated or subturbinate, more or less expanding above, externally rugose at intervals (when weathered often very rough); cup regularly concave, deep; lamellæ thin, distance from each other equal to their thickness, denticulated on their upper and inner edges; transverse dissepiments corresponding to the concavity, and forming the cell or cup, and extending upwards to the margin.

"In this fossil, the rays become in fact subordinate to the dissepiments; and the character would be more correctly defined, by describing the coral to consist of a series of concave discs or inverted cones setting one within the other, having their upper surface marked by radiating rows of denticles. The form is very irregular, varying from small, short, turbinate forms to elongated cylindrical ones in which the diameter scarcely varies throughout. The weathered surfaces present the arrangement of the dissepiments more or less perfectly in numerous specimens. In one or two instances, I have seen specimens where the weathering developed the rays more prominently than the dissepiments, and in such instances the surface is beautifully denticulated."

4. *Chonophyllum magnificum*, Billings.

Chonophyllum magnificum, Billings. Can. Jour., new ser., vol. v, 1860, pp. 264–265, pl. i.
" " Rominger. Geol. Sur. of Mich., vol. iii, pt. ii, 1876, p. 116, pl. xliii.
" " Davis. Kentucky Fossil Corals, pt. ii, 1885, pl. 101, fig. 3; pl. 103, figs. 12, 13, 14.

This species, to which frequent reference has been made, was founded by Billings in 1860 upon a specimen imbedded in a mass of Devonian limestone, Walpole township, Canada West. He was entirely misled by the very peculiar septal formation, supposing the broad septa to represent the interseptal cavities, and the narrow grooves of the calyx to mark the position of the septa. His description reads as follows:

"Short, turbinate, expanding to the width of six or seven inches at a height of four inches and a half; upper surface constituting a nearly flat circular disc, with a rounded cavity in the middle, one inch and a half wide, from which radiate one

* N. Y. Geol. and Pal., 1889, p. 177.

hundred and twenty-five depressed convex ridges; the grooves between them narrow and somewhat angular in the bottom. These ridges are gently curved in crossing the broad flat margin of the cup. The depth of the central cavity is about one inch. A transverse or horizontal section shews that many of the septa (probably one-half of them) reach the center. In a vertical section, extending downwards, so as to cut off the outer extremities of a few of the radiating ridges, it is shewn that the grooves on the floor of the cup indicate the position of the septa, and that the ridges are the interseptal spaces. The structure, as exhibited in this section, consists of excessively thin, parallel, horizontal laminæ (apparently from thirty to forty in the thickness of one line). These laminæ are arched upwards between the septa, the curve corresponding with the convexity of the radiating ridges. In the lower part of the corallite, the interseptal tissue is much coarser. The surfaces of the radiating ridges appear to be covered with small tubercles."

The growth of this species varies from short, broadly explanate forms to those conico-cylindrical in shape. In the latter the calyx diameter is seldom over 6 or 7 cm, while in the former it may reach a breadth of 22 or 23 cm. There is typically a central pit and broadly expanded calicinal margins; no fovea. The septa are alternating in length and vary in number from 75 or 80 to 125 in adult forms. The epithecal covering, structure of the septa, the dissepiments and central structure have been already described in detail under the general description of the genus. Billings states that "this species resembles *Chonophyllum perfoliatum* (Goldfuss), but is much larger, and has double the number of radiating septa." Although in general not possessing *double* the number of septa, it has more septa and is a larger form. The septal layers are more delicate, regular and more strongly curved. Besides being found in Canada West, it has also been collected from the Upper Helderberg limestones of Mackinac island; falls of the Ohio; Charleston landing; Indiana, and it is occasionally met with in the drift.

5. *Chonophyllum belli*, Billings.

Chonophyllum belli, Billings. Can. Nat. and Geol., new ser., vol. ii, 1865, pp. 431–432.

The types of this second species of Billings are deposited in the museum of the Canadian geological survey, Ottawa, and bear the label *Ptychophyllum belli*, in his own handwriting. They were assigned, however, to *Chonophyllum* and described as follows:

"Sub-turbinate, enlarging from a pointed base to a diameter of eighteen lines in about two inches, then becoming more cylindrical. Length, three or four inches; greatest diameter observed, at the cup, thirty lines. Cup, in the largest specimen seen eight lines wide and six lines deep with slightly sloping walls, apparently flat in the bottom with the exception of a rough styliform projection in the center; edge of the cup narrowly rounded, a broad flat or gently convex margin all round

which is nearly horizontal or slightly sloping outwards and downwards. In the inside of the cup there are about seventy thin, sharp, slightly elevated septa, alternately larger and smaller. These, in radiating outward across the broad, flat margin to the periphery, are gradually changed into rounded ribs, some of them half a line wide. The body of the fossil, as shown in several weathered and silicified specimens, is composed of numerous irregular infundibuliform layers which are, in some places, in contact, and elsewhere, separated, sometimes three lines apart. Surface, unknown. This species shows that *Chonophyllum* and *Ptychophyllum* are closely related genera." Manitoulin island, Clinton formation, Canada West.

Through the courtesy of Mr. J. F. Whiteaves, of the Canadian survey, we have had an opportunity of examining one of the best preserved type specimens of this species. The above description is of a *Ptychophyllum* rather than a *Chonophyllum*, and to this genus we were disposed to refer these forms. However, upon an examination of this type, we find no reason for removing it from the genus to which it was referred by Billings. The turbinate form, the central pit in the calyx, the broadly explanate margins traversed by the widening, convex septal ridges, are all suggestive of the genus. These septa do not become angular in the outer area and show no more twisting at the center than may be found in accepted species of *Chonophyllum*. The specimen is silicified in such way as to conceal the actual structure of the septa, but where it is indicated it seems to agree with that already described rather than with that of *Ptychophyllum*. Until more can be known of the internal structure of these corals they with propriety may be retained in the genus. It is a smaller form than *C. magnificum*, with fewer septa. The septal layers are coarser and less strongly bent and the supporting growths are not so well developed, if present at all. Knowing so little of the internal structure of this species and of *C. perfoliatum*, it is difficult to point out any definite characters by which they may be separated. The septa in the latter are but little twisted at the center, but this character is variable in the same species.

6. *Chonophyllum ellipticum*, Hall and Whitfield.

Chonophyllum (*Ptychophyllum*) *ellipticum*, Hall and Whitfield. 23d Rep. of N. Y. State Cabinet for 1869, 1873, p. 233, pl. 9, fig. 13.

"Coral small, subturbinate, laterally compressed, and much distorted in growth; rays somewhat strongly developed and numerous, very slightly twisted as they approach the center of the cup. Calyx shallow, with rapidly ascending sides in young specimens, and spreading nearly horizontally toward the margin in older forms. Exterior of the body covered by a continuous epithecal coating, increasing in strength from below upward. In a vertical section the infundibuliform cups are somewhat distant, broad at the base, with rapidly ascending sides; the spaces between them, and also between the rays, are filled with numerous, irregular, cystose partitions.

"The distinctive features of this species consist in its elliptical outline and distinctively marked rays. There may be some doubt as to its generic relations. The rays are very slightly twisted as they approach the center of the cup, but there is no appearance of a columella. The great development of the rays, and the continuous epitheeal coating, are features which pertain more particularly to *Ptychophyllum* than to *Chonophyllum*.

"*Formation and locality:* In the marly beds at Rockford, Iowa."

An examination of specimens from the same locality (Hamilton group) shows lamellar septa, well-developed horizontal tabulæ through nearly one-half the visceral cavity, and in the outer area a very coarse vesicular structure. After describing his *Cyathophyllum houghtoni* from the Hamilton group of Michigan, Dr. Rominger adds:*

"A coral described by Hall under the name of *Chonophyllum ellipticum*, from the Hamilton group of Iowa, agrees in structure with the described form, but not with *Chonophyllum*."

The specimen figured on plate xxxvi, upper tier, center, shows a structure very similar to that seen in vertical sections of *Chonophyllum ellipticum*.

7. *Chonophyllum ponderosum*, Rominger.

Chonophyllum ponderosum, Rominger. Geol. Sur. of Mich., vol. iii, pt. ii, 1876, p. 117, pl. xliii.

This peculiar coral, in regard to the generic relations of which there is no doubt, is from the lower Devonian strata of Michigan. It was thus originally described:

"Patellate, depressed, conical polyparia of irregular, unsymmetrical, clumsy growth, with gemmation from the center of the calyces, of single new cells, or, in rare instances, of from two to four confluent or imperfectly defined calyces. End cells shallow, explanate at the margins, more abruptly depressed in the center, which is surrounded by a cycle of low linear crests uniting in it with twisted ends. Expanded marginal part radiated by flat, broad, band-like plications of papillose surface. The specimens are all formed of a heavy, compact mass of amorphous, white, ivory-like carbonate of lime, or partially silicified, and with scarcely a trace of the organic structure preserved; only in a few specimens could enough of it be seen by which to recognize the generic relations of the specimens and their correspondence with *Chonophyllum*.

"It does not seem to be the mode of petrifaction which obscures the structure, as we find this coral in many different localities associated with other corals exhibiting the finest details of structure, while they everywhere present the same massive, compact condition. The coral appears to have, during the progress of its growth, filled out all its cellulose cavities as soon as the fleshy parts of the animal abandoned them.

"It occurs rarely in the Upper Helderberg limestone, but is abundant in certain layers of the Hamilton group of Thunder bay, and is also found in Little Traverse bay."

*Geol. Sur. of Mich., vol. iii, pt. ii, p. 105.

We have collected a seriés of specimens from the locality producing the types (Phelp's quarry, Alpena, Michigan), and from these have been able to learn something further in regard to the internal structure. The septa are made up of superposed layers, convex upward, as in *C. magnificum*, but they are coarser and more distant in proportion to the size of each septum. They are also flatter, being less deflected at their edges. In specimens in which they could be satisfactorily counted they average from 15 to 20 to the cm and occupy a corresponding position in neighboring septa as though deposited simultaneously. The supporting growths are present, rising vertically through a series of the septal layers. The interseptal cavities are narrower and less distinctly defined than in type forms. We were unable to find a radial section clear enough to show defined vesicles in the outer area, but toward the center they come into view as the transverse leaflets between the contorted septa, taking the place of true tabulæ.

There are several considerations which lead to the conclusion that the solid deposits of carbonate could not have been made by the polyps themselves :

1. Some of the associated fossils are filled in just as completely with material indistinguishable from that of *C. ponderosum*. The best example is that of *Strombodes alpenensis*, Rom. Numerous corals and crinoid stems were collected, showing a similar structure but in which the deposit was less compact and hence softer. A colony of *Acervularia* with a height and diameter of about ten feet showed patches and layers of this material nearly or quite obscuring the structure.

2. That these deposits did not take place directly in the inhabited calyx is evidenced by the layered structure and supporting growths. From the lower abandoned portions of the corallum the polyp was, in the main, completely shut off by septal layers and dissepimental structures.

3. The process would have been uneconomical and highly wasteful of building material. So far as we can see, it would have been of no special value to the polyp. Solid deposits may be found in some modern, delicately branching corals, evidently for the purpose of strengthening them, but no such use could be assigned in the case of a simple, turbinate form.

4. Spherulites, corresponding in appearance and structure with "orbicular silica," were found imbedded in this solid deposit of a specimen. They were numerous about the calyx, and on eating away the under side of the specimen with acid they were revealed in still greater numbers, along with crystals of iron pyrites. Each spherule consists of a rounded nucleus of silica, whitish and opaque to the eye, but crystalline in struct-

ure, surrounded by successive coatings of the carbonate. The silica must have been deposited from infiltrating water *previous* to the deposition of the calcium carbonate.

5. Thin sections, under polarized light, show a uniform mass of fine, interweaving crystals, many of which have their axes turned in the same direction, so that upon revolving the microscope stage the field extinguishes in large irregular patches. Sections of *Strombodes alpenensis* are identical in appearance, while those from the *Acervularia* above mentioned differ only by being more coarsely crystalline.

6. Portions of specimens, especially through the center, have been found from which the deposit is absent. It is not improbable that diligent search may bring out specimens from which it is entirely so.

This species is separated from all others by its more irregular growth, by more numerous septa, which are decidedly twisted at the center, and by the solid deposits of calcium carbonate.

8. *Chonophyllum sedaliense*, White.

Chonophyllum sedaliense, White. Cont. to Paleontology,* 1880, Nos. 2–8, p. 157, pl. 39. fig. 1*a*.

The original description of this species reads thus:

"Corallum moderately large, approximately straight, the angle of divergence of its sides being quite small; calyx apparently rather shallow; rays numerous; surface rough by the presence of numerous projecting successive calyx-borders, and by coarse, irregular longitudinal striæ. Only one example has been obtained, and that has been broken off at the lower end, and also somewhat crushed. Its full length was probably about 130 millimeters, and the diameter of the calyx about 30 millimeters.

"Position and locality. Near the top of the Chouteau limestone (Kinderhook division of the Subcarboniferous series), Sedalia, Mo., where is was obtained by Professor G. C. Broadhead."

The figure given bears some general resemblance to that of *Chonophyllum elongatum*, E. and H.

Some half dozen specimens of this form, kindly sent by Professor Broadhead, are now before me. They have a conico-cylindrical growth, strongly curved near the base, and are all more or less compressed. The specimen in which the structures are best preserved had an exceptionally long cylindrical growth, this fragment being 14.5 cm in length and as broad at one end as at the other (3.5 to 4 cm). A polished cross-section shows 170 very thin, alternating septa, the primaries reaching the center.

---

* Extracted from the 12th Annual Report of the U. S. Geol. and Geog. Survey of the Territories for the year 1878.

while the secondaries do not extend more than one-third of this distance and being, at their inner edges, curved toward the primaries, at times apparently uniting with them. The fovea is indicated upon one side in this section by a dwarfed primary septum and a very decided pinnate arrangement of the neighboring ones, such as occurs in *Aulacophyllum*, E. and H. Between the septa are seen the cut edges of the dissepiments, most abundant in the outer area, gradually diminishing toward the center. A more complete study of the internal structure will be made before locating this species, but sufficient has been pointed out here to show that it is not the *Chonophyllum* which we have attempted to characterize.

9. *Chonophyllum radum*, Hall.

Chonophyllum radum, Hall. Corals of the Niag. and Up. Held. Groups,* 1882, p. 6.
" " Hall. Geol. of Ind., 12th Rep., 1882, p. 272, pl. 15, figs. 1–4.

This species was thus originally characterized by Professor Hall:

"Corallum simple, turbinate, straight or slightly curved, acute at the base, regularly expanding to the calix; exterior with numerous abrupt constrictions, and fine concentric striæ; external costæ very distinct; height 35 mm; diameter of calix 20 mm; depth 10 mm; sides slightly concave; a flat space at the bottom 5 mm in diameter; number of lamellae 70, flat, and of nearly uniform size at the margin, becoming thinner and alternating in size below; the principal ones extending to the center, where they are twisted and very slightly elevated.

"*Formation and locality.*—Niagara group, Louisville, Kentucky."

We have seen no authentic specimen of this species, and this description, based simply upon external characters, is far from being so satisfactory as we could desire. With the exception of the "flat" septa in the outer area, there is nothing about it to suggest the genus *Chonophyllum*. The general form of the specimens figured and the thin angular septa in figure 3 seem sufficient for their rejection from this genus.

10. *Chonophyllum rapax*, Hall.

Chonophyllum rapax, Hall. 35th Rep. N. Y. State Mus. for 1881, 1884, pp. 410–11.

Although not accompanied by any figures, the description of this species is more complete, and it can more positively be asserted not to be a *Chonophyllum*.

---

*Advance sheets from the Thirty-fifth Rep. of the N. Y. State Mus. for 1881, 1884, p. 410.

"Corallum simple, broadly turbinate, regularly expanding; exterior with numerous concentric wrinkles and striations. Externally there are numerous slender processes, quite evenly distributed, which served for attachment and support; when exfoliated the exterior has a somewhat compressed vesiculose appearance; corallum consisting of thin, superimposed laminæ; height 35 mm; diameter of calix 60 mm; depth 12 mm; for a distance of 20 mm from the margin it is gently sloping, then nearly vertical; a convex space at the bottom 15 mm in diameter; tabulæ thin; fossette small, deep, not extending on the side of the calix; number of lamellæ 160, alternating in size, the smaller ones rudimentary, not more than one-sixth the thickness of the others; near the margin the larger ones are broad, angular, having a width of about 1.50 mm becoming thinner as they approach the center where they are twisted and elevated, forming a false columella.

"This species has nearly the same form as *P.* [*Ptychophyllum*] *fulcratum*; it has also similar processes for attachment, and might, on a cursory examination, be mistaken for that species, but it is much more distinctly composed of thin, invaginated laminæ; the lamellæ are decidedly alternating in size and there are well developed tabulæ.

"Formation and locality. Niagara limestone, Louisville, Kentucky."

The deep fovea, angular septa, well developed tabulæ, invaginated laminæ, false columella, and radiciform processes leave no doubt but that we have here a genuine *Ptychophyllum*.

In the plates of Kentucky corals,* for which no text has yet been issued, Mr. Davis figures two supposedly new species of *Chonophyllum* from the Devonian and assigns the specific names, *nanum* and *multiplicatum*. The photographs reveal no structure in either which can bring them into this genus.

From this list of species we have found *C. perfoliatum*, *C. magnificum*, *C. ponderosum* and possibly *C. belli*, which possess structures sufficiently closely related to permit of their being grouped under one genus.

Description of New Species.

(Plate 8, figure 6.)

We have made a study of two forms, not previously described, which are most properly referred to this group, and we append descriptions. The first is of a specimen collected from the Upper Silurian of Conjepruss, Bohemia, by Dr. Rominger, and described here with his permission. The name *pseudohelianthoides* is of his suggestion. The second species is founded upon a specimen from Louisville, Kentucky, collected by Mr. G. K. Greene, in whose honor it is named.

*A Monograph of the Fossil Corals of the Silurian and Devonian Rocks of Kentucky, pt. ii, 1885, pl 78, fig 6, and pl. 80, figs. 11, 12 and 13.

Chonophyllum pseudohelianthoides, n. sp.

(Plate 8, figure 6.)

Simple, short conical in growth, with a central pit in the calyx, 1.5 cm in diameter and 5 mm in depth. The side walls of this pit curve upward and outward, and the outer margins are regularly reflexed as in *Cyathophyllum helianthoides*, Goldf. The bottom of the calyx is flat for a distance of 7 or 8 mm and shows no fovea. The length of the specimen was about 2.5 cm, and the expanded calicinal margins reached a breadth of 5 cm. Only traces of the outer epitheeal covering remain. There are 72 alternating septa, the secondaries terminating at the outer edge of the pit, while the primaries reach the center without any twisting. They are thin in the vicinity of the pit, but gradually widen into low granulose, convex bands, 1.5 to 2 mm in breadth, leaving very narrow grooves in the outer reflexed portion of the calyx. These septa are formed by radial curved plates superposed as in other species of the genus, but less regular in form and position. They average about 30 to the cm. Radial sections through the septa give a vesicular structure instead of the parallel edges seen in *C. magnificum* and *C. ponderosum*. The septal layers are here shown to be quite irregular and anastomosing so as to form elongated, narrow vesicles. The interseptal cavities are not so well defined as in typical forms of the genus, the septal layers passing into them, abutting against one another, and in places interweaving. The vesicles are relatively coarse and irregular toward the center, passing into the typical transverse leaflets and not forming tabulæ.

Formation and locality: Upper Silurian, Conjepruss, Bohemia.

This species is distinguished from previously described forms by its very regular, reflexed growth and the irregularities in its septal structure.

Chonophyllum greenei, n. sp.

(Plate 8, figure 7.)

Simple, of conico-cylindrical growth, having an original length of about 5.5 cm and a calyx diameter of 3 cm. The base has been lost, and but a faint indication remains of the outer covering. The successive calyces in the lower half of the corallum are oblique to the axis, as though it had been compelled to grow away from an obstruction. The calyx has a central pit, 1.5 cm in diameter and 1 cm deep, with a roughened horizontal bottom, slightly depressed around the outer edge, but showing no fovea. The side walls of the pit are nearly vertical, and at the top round off into a horizontal ring-like expansion about 1 cm broad. The septa number 72 and are of two orders, the secondaries terminating at the outer wall of the pit, while the primaries reach the

center without any decided twisting. They are roughly granulose on the upper surfaces, sharp in and about the pit, but toward the outer area becoming broad and convex, attaining a width of 1.5 mm and leaving narrow interseptal grooves. These septa are formed of curved layers, convex upward, which are typically deflected downward at their edges to form the side faces, but which frequently pass into the poorly defined interseptal cavities and abut against those of adjoining septa. Compared with *C. magnificum*, they are coarser and more distant in proportion to the size of the septum and less strongly curved. Apparently in corresponding position, they give an appearance of invaginated cell-cups to the corallum. Vertical tangential sections show at times a central radial supporting plate, extending upward through a number of layers, very suggestive of that to be described for *Cyathophyllum helianthoides*. These plates may be double, branching and irregular. Radial sections through the septa show the edges of these layers curving upward and outward, intersected by the supporting growths, and forming elongated, flat vesicles somewhat as in the preceding species. Between these septal plates more delicate vesicles are interposed, so that in grinding down such sections it is not easy to tell where the interseptal cavity ends and the septum begins.

The central part of the corallum has been dissolved and only the outer silicified portion remains, so that the central structure cannot be studied so thoroughly as desired. The vesicles are well developed, as shown in radial sections through the interseptal cavities and in vertical tangential sections uniting the septa. They are irregular in size and arranged in curved rows inclining upward and outward. In grinding the specimen down and examining it at the successive stages, it was found that no well defined tabulæ are present. Transverse leaflets, concave upward or flat, are placed in the wedge-shaped interseptal cavities, and rather closely approximated. When placed at approximately the same height in neighboring cavities they simulate irregular tabulæ for short distances.

Formation and locality: Niagara limestone, Beargrass creek, near Louisville, Kentucky.

This species is less turbinate and expanded than other forms of *Chonophyllum*. Its shape is more suggestive of the larger, conico-cylindrical forms of *C. magnificum*. It is readily distinguished from these by the irregularities in the septal structure, the layers being coarser, more distant and less curved.

Nearest Relatives.

General Relations.—The separation of this genus from those closely related to it, and most liable to be mistaken for it, becomes a matter of

some importance. It has been confused more with *Omphyma* and *Ptychophyllum* than with any other genera; more, however, from external resemblance than from actual similarity in details of structure. We present here the essential characters of these genera and the points by which typical forms of each may be separated from *Chonophyllum*. One will not work long, however, before he encounters intermediate forms, the disposition of which will have to depend upon mere individual opinion. These make it all the more necessary that our generic characters be definitely drawn. We do not turn over our land to our neighbor simply because the line fence is down in places.

Omphyma, Rafinesque and Clifford, 1820.

The type of this genus is *O. turbinata*, Fougt., sp., several Gotland specimens of which we have examined along with other foreign and American forms, among which is a series from point Detour and Drummonds island, lake Huron, in excellent state of preservation for study.

The general shape of the corallum and calyx is, as in *Chonophyllum*, short conical, turbinate, or conico-cylindrical, with basin-like calyx and explanate margins. There seems to be no outer covering which can be differentiated into a theca and an epitheca, but a single, protective, epithecal covering, showing plainly through it the body structure of the corallum. The best preserved specimens show that it was deposited in exceedingly fine encircling bands or ridges, suggesting the weatherboarding on the side of a frame house. The so-called heavy accretion-ridges of growth do not arise from the epitheca, but from successive contractions and expansions of the corallum itself. Likewise the strong and characteristic radiciform processes come from neither epitheca nor wall, but are expansions of the body structures.

The corallum is made up of a series of superposed cell-cups, which form numerous horizontal tabulæ through the central area. The septa are formed by radial infoldings of these continuous cups, sometimes so sharply bent as to form thin septa in the outer area. Usually, however, the septa here are broad and angular, *i. e.*, show a sharp median ridge giving a roof or tent shape on the upper side. No supporting growths are developed. When viewed in vertical tangential sections these cup-layers are seen to curve downward through the interseptal cavities, from septum to septum, forming a series of irregular scallops, concave upward through the interseptal cavities, the upturned points marking the positions of the septal ridges. In radial sections, giving side views of these layers, they are seen to have an additional scalloped structure, now convex upward, and forming coarse irregular vesicles. It is thus seen that the septa and the interseptal cavities are not clearly differentiated as in

the typical *Chonophyllum* and in the rugosa in general, although from additional deposits of calcium carbonate a nearly lamellar septum may at times be formed.

The septa typically terminate some distance from the center, leaving a broad, flat central area. In certain specimens the sharp septal foldings of the cell-cups may continue to near the center as low ridges upon the tabulæ. Four foveæ are developed in typical forms, but generally one only is at all distinctly defined. The broad longitudinal bands on the epitheca mark the positions of the interseptal cavities.

The following points of structure will then ordinarily serve for the separation of *Omphyma* from *Chonophyllum* :

1. Strong radiciform processes.
2. Broad, well developed tabulæ.
3. Infolding of the cell-cups to form sharply crested or angular septa.
4. Absence of supporting processes.
5. The coarse, subvesicular structure of the interseptal cavities.
6. The generally broad, smooth central area.
7. The presence of one or more foveæ.
8. The broad costal bands representing the interseptal cavities.

Ptychophyllum, Edwards and Haime, 1850.

The type of this genus, as given by the founders, is *P. stokesi*, E. and H., from Drummonds island, lake Huron. Owing to the development of radiciform processes, similar to those found in *Omphyma* from the same locality, Dr. Rominger has redescribed this species as *Omphyma stokesi*.* According to this authority, forms in all other respects similar to *P. patellatum*, from Gotland, which Zittel gives as the type,† occur at the falls of the Ohio with similar processes.‡ We have been able to examine a few specimens of these two species from the typical localities.

The form of corals referable to this genus is, in general, similar to those of *Chonophyllum* and *Omphyma*. In *P. patellatum* the calyx margins are often strongly and irregularly reflexed. The epithecal covering is generally strong and persistent. One fovea is present, at times becoming very distinct. The general structure of the corallum, as regards the formation of the cell-cups and their radial infolding to form the septa, is as has been described for *Omphyma*. We have then *angular* septa in the outer area, gradually becoming thinner toward the center, where they are twisted into a false columella and form an elevation in the calyx. This columella was regarded by Edwards and Haime as distinguishing

*Geol. Surv. Mich., vol. iii, pt. ii, 1876, pp. 119–120.
†Handb. der Pal., vol. i, 1880, p. 229.
‡Geol. Surv. Mich., vol. iii, pt. ii, 1876, p. 120.

this genus from *Chonophyllum*.* Nearly or quite as much twisting, however, may occur in *C. ponderosum*, so that this character alone cannot be relied upon for their separation. No spicules or supporting growths are found in these type forms. Distinct and, at times, strong tabulæ are found in the central area. The layers curve downward between the septal ridges and form coarse, subvesicular structures in the outer interseptal cavities, just as in *Omphyma*. The broad bands upon the epitheca correspond to the interseptal cavities and the fine, longitudinal grooves mark the position of the septa.

The following details of structure will ordinarily serve for its complete separation from *Chonophyllum*:

1. The more persistent epitheca and occasional radiciform process.
2. The well developed tabulæ through the central area.
3. Cell-cups forming sharp or angular septa by their radial infoldings.
4. Absence of supporting growths.
5. False columella and common elevation of the bottom of the calyx.
6. The coarse subvesicular structure of the interseptal cavities.
7. The generally distinct fovea.
8. The broad longitudinal bands upon the epitheca representing the interseptal cavities.

We have met a collection of some 7 or 8 specimens from the Helderberg group, of Kentucky, 40 miles south of Louisville, in which the characters of these two genera are to some extent combined. They have an irregular *Ptychophyllum* growth, epitheca well preserved, a spongy columella projecting from the bottom of the pit, one well defined fovea and, occasionally, radiciform processes. On the other hand, the septa, as seen in the outer area of the calyx, are not angular but rounded and convex as in *Chonophyllum*, and the broad longitudinal bands mark the position of the septa. Unfortunately the specimens are so solidly silicified that but little of their actual structure can be made out. Basing our judgment simply upon the external characters, we prefer to assign these forms to *Ptychophyllum*.

Cyathophyllum, Goldfuss,1826.

The simple forms of this genus are usually readily separated from *Chonophyllum* by the lamellar septa and the development of tabulæ. Simple forms, however, of the species still commonly known as *Cyathophyllum helianthoides*, Goldf., are more closely related, and it may be well to separate the two, now that a form of *Chonophyllum* is known so similar in general appearance. These are turbinate, with regularly and strongly

* Brit Foss. Cor., pt. i, 1850, p. lxix.

reflexed calicinal margins, leaving a monticulose rim around the central pit. The fovea is obsolete or merely indicated. A thin epithecal covering is present which shows the broad bands and narrow grooves arranged as in *Omphyma* and *Ptychophyllum.* The septa, as seen in the calyx, are thin about the pit but broad and angular in the outer area. They are of two orders, the secondaries terminating at the pit and the primaries reaching the center without any decided twisting. Cross-sections show these septa to be thin and lamellar, becoming flexuous and ill defined in the outer area. In this region they are at times strongly carinated, the lateral plates either in corresponding position on opposite sides of the same septum or alternating in position. Vertical tangential sections show the thin, flexuous septa with delicate plates arching downward from each side to the center of the interseptal cavities, generally placed at the same height on opposite sides of the same septum and giving an appearance suggestive of the *Chonophyllum* septal structure. Considerable irregularity occurs in these layers and, at times, continuous horizontal plates are introduced which may be traced across a number of septa. In radial sections these plates give with their cut edges a series of parallel lines curving upward and outward from the center, while the coarser carinæ cross them at right angles downward and outward from the center. A well defined vesicular structure occurs in the broad interseptal cavities. The tabulæ are poorly developed through the central area.

It may be distinguished from *Chonophyllum* then by the following points of structure:

1. The lamellar septa.
2. The much broader interseptal cavities.
3. More complete tabulæ.
4. The carinal structures.
5. The broad longitudinal ridges on the epitheca representing the position of the interseptal cavities and the narrow lines the septa themselves.
6. The general form of these corals distinguishes them from all species except *C. pseudohelianthoides.*

Horizons and Distribution.

The only known European forms are *C. perfoliatum* and *C. pseudohelianthoides.* Goldfuss' specimen of the former is from the Upper Silurian (Niagara) of the island of Gotland, while Edwards and Haime's specimens were collected from the Devonian rocks of Brulon, France, and Torquay, England. The latter species is from the Upper Silurian of Conjepruss, Bohemia. The remaining species are entirely American, as

these two are exclusively European. *C. magnificum* is the most abundant and widely distributed of any of these. According to Dana, it is characteristic of the Corniferous.* It was obtained by Billings from Walpole township, Canada West, and by Rominger and others from the Upper Helderberg group of Mackinac island; falls of the Ohio; Charleston landing, Indiana; and distributed through the drift. *C. belli* is from the Upper Silurian (Clinton) of Manitoulin island, lake Huron. *C. ponderosum* "occurs rarely in the Upper Helderberg limestones, but is abundant in certain layers of the Hamilton group of Thunder bay." It occurs also in the same formation at Little Traverse bay, and has been met with in the drift. *C. greenei* is from the Niagara limestone near Louisville, Kentucky.

The range of the genus is thus through the Upper Silurian and two lower divisions of the Devonian, reaching its maximum development in the Upper Helderberg. Ushered into the warm molluscan seas, surviving the changes which inaugurated the Devonian, finding here conditions most favorable for its development, by the close of the Hamilton its life energies had been spent, and, shrouded only by the sea bottom's slime and ooze, it passed from scenes of active existence.

NOTE: In reply to a letter of inquiry concerning the structure of certain of these corals, Professor James Hall writes as follows:

"In regard to *Chonophyllum magnificum*, I may say that I know no other coral having the same type of structure. I have had slices cut from well preserved specimens in several directions, and all show a peculiar membraniferous structure such as I have been unable to obtain from any other cyathophylloid corals or from any other coral which I have examined. When I referred species to *Chonophyllum* I had not made sections for critical study. I have since concluded that *Chonophyllum niagarense* should be referred to *Cystiphyllum*, though this one and some other forms present a very unusual appearance for that genus. Of *C.* (*Ptychophyllum*) *ellipticum*, I do not at this moment recall the structure. All these specimens are now in the American Museum of Natural History, in the city of New York, and have been out of my hands for sixteen years.

"I cannot at this moment recall the characters of *C. vadum* and *C. eapax*, nor do I think I have had sections made of them. I cannot speak positively, but I greatly doubt whether they will show the peculiar superimposed membraniform layers or tissue characteristic of *C. magnificum*."

NEW YORK STATE MUSEUM, *December 26, 1892.*

---

* Manual of Geology, 1880, p. 261.

Explanation of Plate 8.

Figure 1.—Photograph of the original Gotland specimen figured by Goldfuss and now deposited in the museum of the university of Bonn; natural size. Very kindly prepared by Dr. Carl Schlüter.

Figure 2.—A vertical section of *Chonophyllum magnificum* through the outer area, showing the septa formed of delicate superposed layers. Under a magnifier the flat faces of the supporting processes may be seen as they pass upward through the successive septal laminæ. Between the broad septa are the narrow, vesiculose interseptal cavities. Magnified 2 diameters.

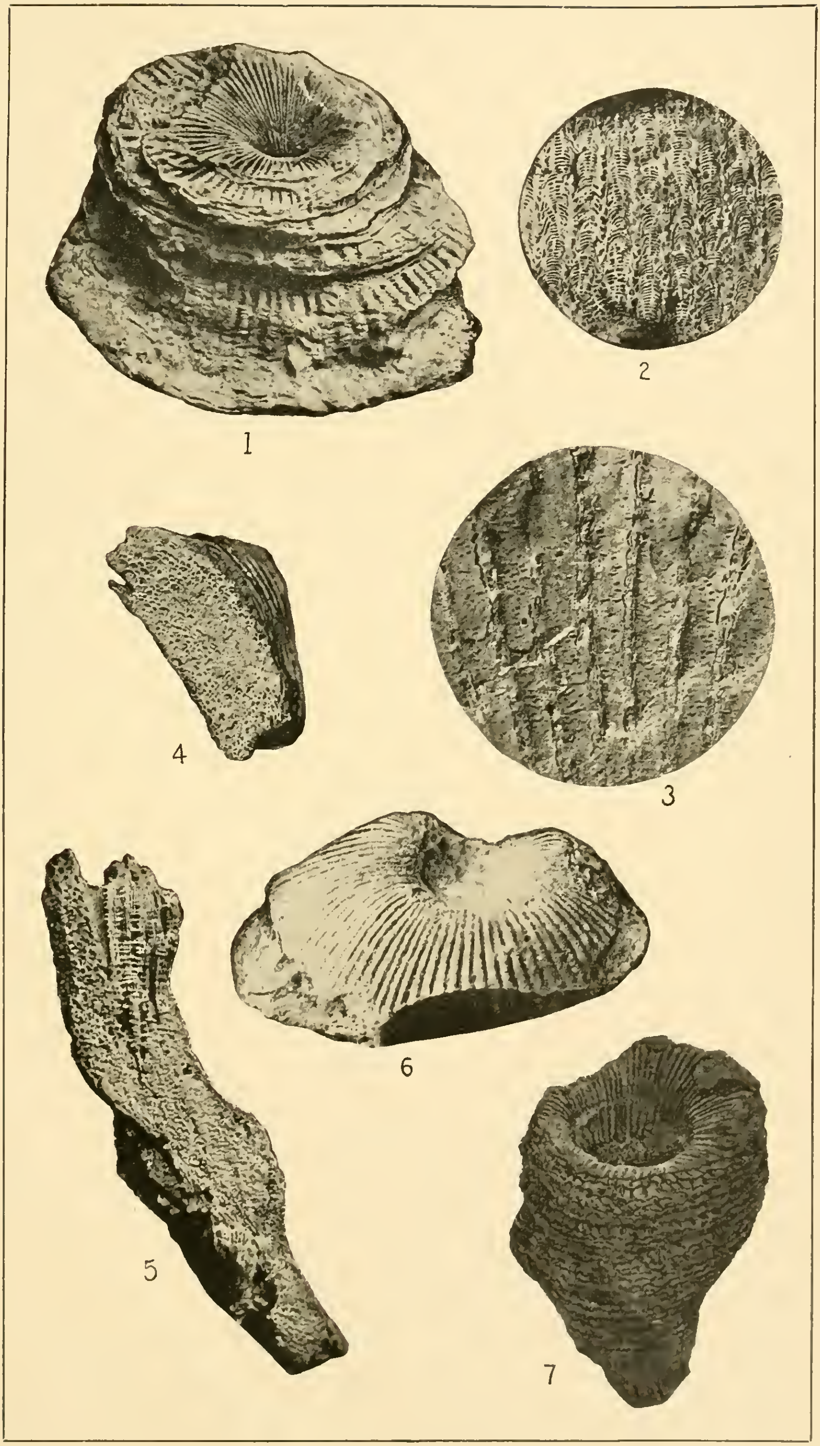
Figure 3.—A view of the under side of the septal layers taken from a large drift specimen of *C. magnificum*. The form and arrangement of the supporting processes, as seen in cross-section, are here shown. In two places near the top of the figure the layers in adjoining septa are seen to be continuous through the intervening interseptal cavity, arching upward and assisting in the formation of the vesicular structure. Magnified 2 diameters.

Figure 4.—A view of the narrow interseptal cavity, showing the vesicles in *C. magnificum*. The coarser vesicles are probably formed by the septal layers as shown in figure 3. Magnified 1¼ diameters.

Figure 5.—Much of the structure of *C. magnificum* is shown in this figure. The lower portion is the base of the specimen and the upper is the outer edge of the calyx, the section being vertical and very near the center. Near the top of the figure, along the upper side, are shown the vesicles of the interseptal cavity, and below them a side view of the septal layers and the edges of the supporting processes. A view of the side face of the septum, with its blunt granulations, appears over the middle third of the figure, while at the bottom is seen the thin, angularly wavy septa of the central area. The irregular transverse leaflets, instead of tabulæ, here fill the interseptal cavities. Magnified 1¼ diameters.

Figure 6.—*Chonophyllum pseudohelianthoides*, n. sp. Upper Silurian, Conjepruss, Bohemia; natural size.

Figure 7.—*Chonophyllum greenei*, n. sp. Niagara, Beargrass creek, Louisville, Kentucky; natural size.



THE GENUS CHONOPHYLLUM.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 283-300, PL. 9

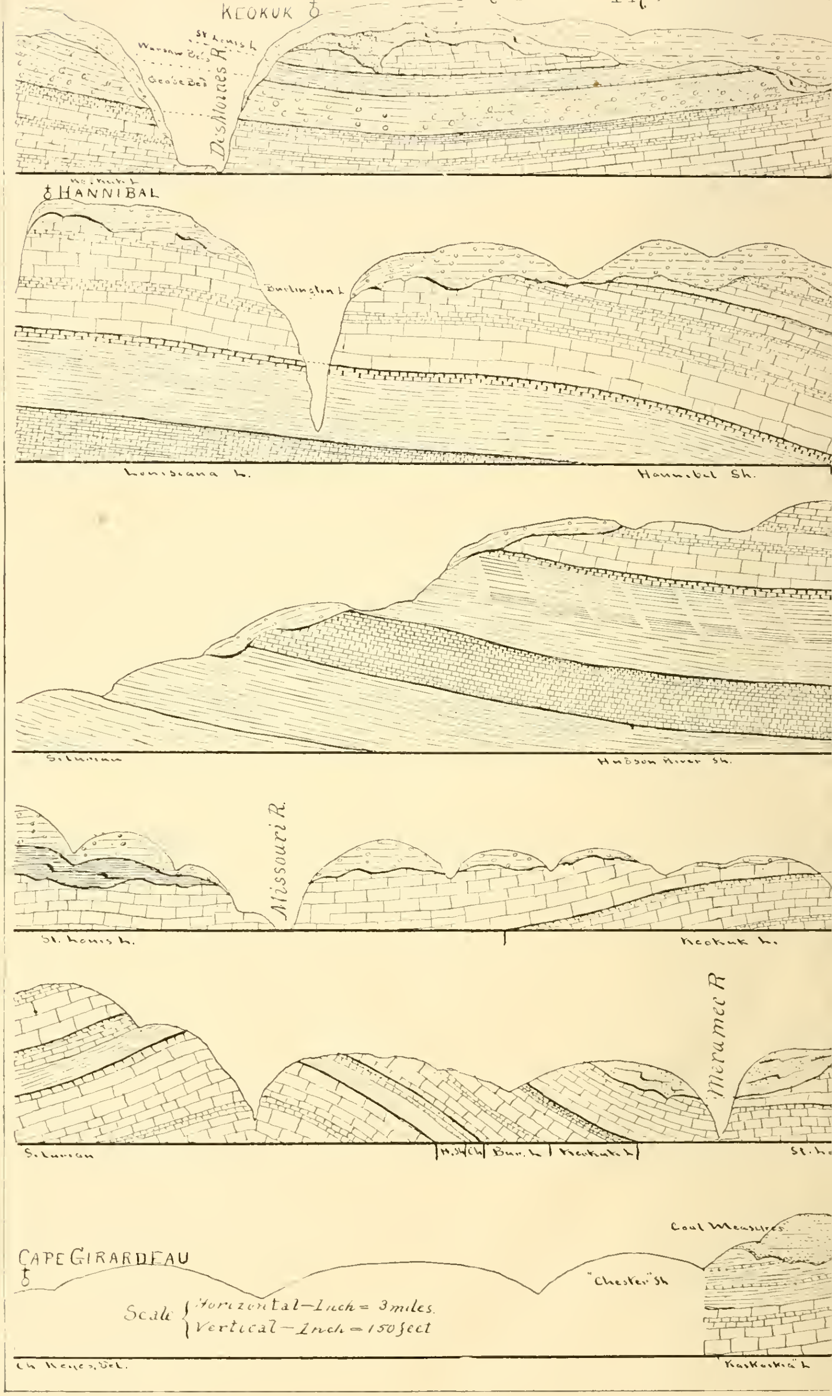
THE PRINCIPAL MISSISSIPPIAN SECTION

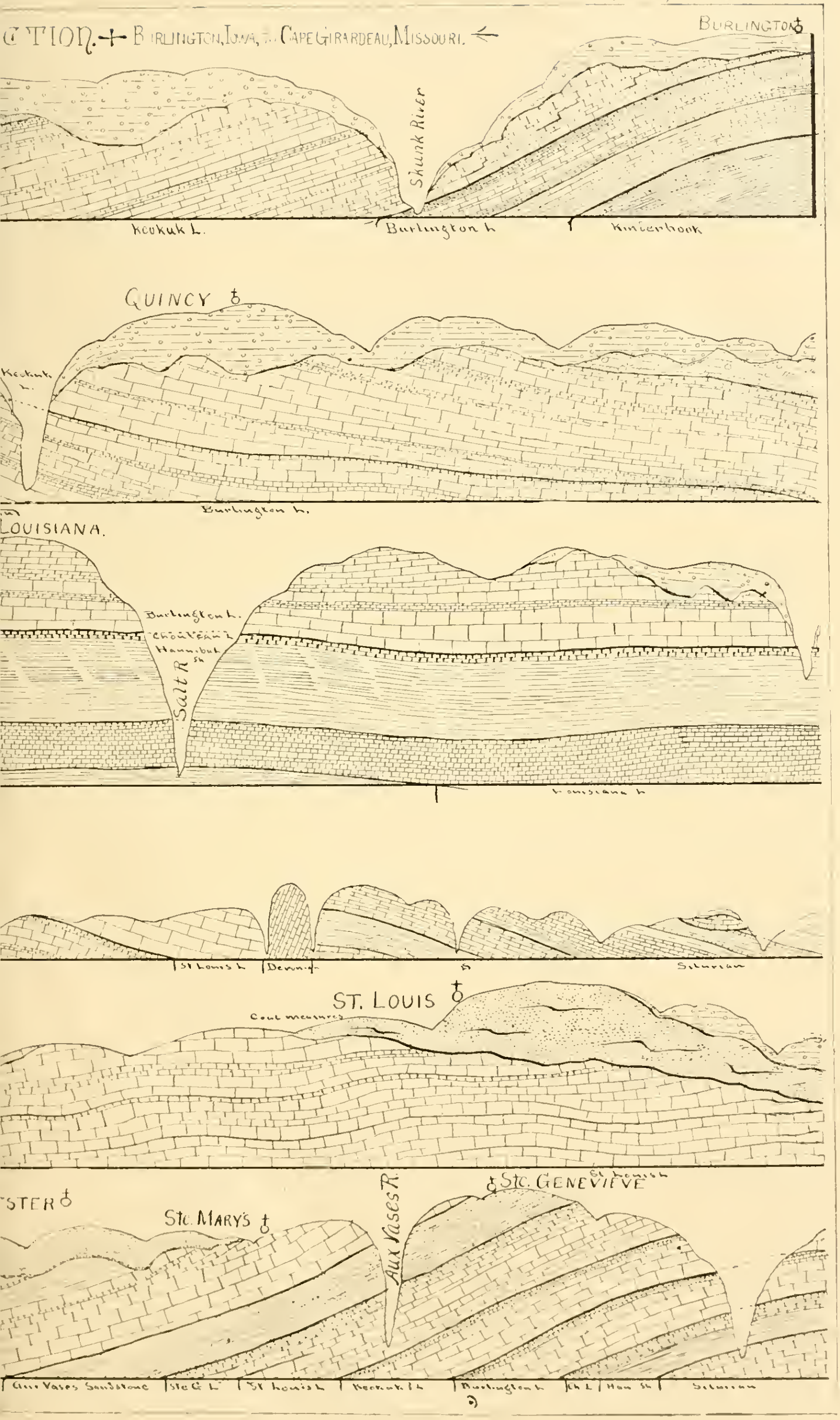
BY

CHARLES R. KEYES

ROCHESTER
PUBLISHED BY THE SOCIETY
JUNE, 1892

THE PRINCIPAL MISSISSIPPIAN




CTION. BURLINGTON, IOWA, ... CAPE GIRARDEAU, MISSOURI.
BURLINGTON
Skunk River
Keokuk L.
Burlington L.
Kinderhook
QUINCY
Keokuk L.
Burlington L.
LOUISIANA.
Burlington L.
Chouteau L.
Hannibal Sh.
Salt R.
Louisiana L.
St Louis L.
Devonian
Silurian
ST. LOUIS
Coal measures
STER
Ste. MARY'S
Aux Vases R.
Ste. GENEVIEVE
St. Louis
Aux Vases Sandstone
Ste G. L.
St Louis L.
Keokuk L.
Burlington L.
Ch. L.
Han. Sh.
Silurian

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 283-300, PL. 9 JUNE 3, 1892

THE PRINCIPAL MISSISSIPPIAN* SECTION.

BY CHARLES R. KEYES.

(Presented before the Society August 25, 1891.)

CONTENTS.

INTRODUCTORY REMARKS.

More than half a century has passed since the rich and varied faunas of the later Paleozoic rocks of the continental interior first began to attract attention. From the beginning an exceedingly active and ever-growing interest was taken in the various forms of ancient life represented, and, as a matter of consequence, the geological history of the region was approached from the biological rather than the stratigraphical side.

*The term Mississippian as here used is a substitute for "lower Carboniferous" as generally applied now to certain rocks in the Mississippi valley. The name was originally suggested in this sense by Alexander Winchell, and has recently been somewhat modified and applied by H. S. Williams. See Bull. U. S. Geol. Sur., no. 80, 1891, p. 135.

Especially was this the case along the line of the Mississippi river, where the most important exposures of the strata in question occur.

The relations of the most important horizons of the lower Carboniferous in the upper Mississippi valley were early made out by Owen and others, and although Owen's views underwent considerable change during the dozen years that he was engaged in studying these rocks, his subdivisions have been practically the basis of all subsequent classifications. In the main they have been adopted everywhere, notwithstanding the fact that a considerable diversity of opinion always has existed in respect to the minor stratigraphical details.

In the naming of the several assemblages of beds, the leading and most widely known terms that have been applied have been taken from localities situated on the "Father of Waters." The Mississippi section, therefore, becomes the most important of all in the correlation of the lower Carboniferous rocks of the great interior basin. For this reason it was that recently all the original localities were visited, the various exposures examined in detail, their relationships with each other and with the overlying and underlying strata particularly noted.

The nominal history of the major subdivisions of the Paleozoic of the Mississippi basin need not be reviewed in this place. Suffice it to mention that the term Subcarboniferous had in the beginning a very different meaning from what it has had of late years. As originally proposed by Owen * the name was used merely to indicate an indefinite series of limestones below the coal-bearing strata of the interior. Subsequently † the same author limited the formation below to the blue, fossil-bearing limestones now known as the Cincinnati beds. In was in 1847, when Owen and Norwood ‡ gave the "black slates" as the upper limiting member of the Devonian, that "Subcarboniferous" was still farther restricted, thus for the first time giving the name Subcarboniferous the meaning which has been generally attached to it of late years.

The most familiar names assigned to the subdivisions of the Carboniferous along the Mississippi river are ten in number, viz: Chouteau, Kinderhook, Burlington, Keokuk, Warsaw, St. Louis, Ste. Genevieve, Chester, Kaskaskia, Coal Measures.

Typical Sections along the Mississippi River.

A few of the most characteristic sections have been selected for notice here, and their lithological details are briefly explained. By comparison with the general section (plate 9) it is thought that the stratigraphical

* Rept. Geol. Rec. Indiana, 1837 (1839), p. 12.

† Rep. on Min. Lands of the United States, 1840, p. 14.

‡ Researches on the Protozoic and Carb. Rocks of central Kentucky during the year 1846 (1847).

relations according to the present understanding can be pointed out in the briefest possible manner. These sections are taken at places where the most minute and satisfactory information is to be obtained, and they assume their names from these localities. They are all marked on the general section.

The Burlington Section.

	Feet.
10. Impure and often somewhat clayey thinly bedded limestone with chert nodules and seams...	20
9. Gray, coarse grained encrinital limestone with occasional clay partings and some flint....	30
8. Buff calcareous and siliceous shales with thin limestone and flint bands..	23
7. Brown and gray encrinital limestone, compact and heavily bedded, with thin clay partings....	27
6. Rather soft buff limestone, probably somewhat magnesian, apparently sandy locally	5
5. Gray oolite....	4
4. Soft, fine grained, yellow sandstone, highly fossiliferous....	6
3. Gray, impure limestone, fragmentary, with often an oolitic band below..	9–13
2. Soft, fine grained bluish or yellowish clayey sandstone passing into sandy shales in places....	20–30
1. Blue clay-shale, fossiliferous, shown by borings to extend 50 to 100 feet or more below the water level; exposed....	50

All beds below number 6 are regarded as Kinderhook. Numbers 7 and 8 form the lower Burlington limestone; numbers 9 and 10 the upper Burlington limestone.

Keokuk Exposures; Tabor's Saw-mill.

	Feet.
9. Drift and loess	10
8. Soft brown or yellowish sandstone passing into a fine grained conglomerate in places, irregularly cross-bedded and lying unconformably upon the next; exposed	10
7. Blue and ash-colored brecciated limestone, indistinctly bedded locally and passing elsewhere into regularly bedded layers....	25
6. Brown, impure arenaceous limestone, heavily bedded....	4
5. Blue, calcareous clayey shale....	10
4. Impure limestone, massive and weathering brown....	7
3. Clay-shales with occasional limestone bands and abundant little crystal grottoes—the "geode-bed"	35
2. Thinly bedded somewhat shaly limestone.	5
1. Blue encrinital limestone, heavily bedded and more or less highly fossiliferous; exposed....	45

Below number 1 of this section is the Keokuk group of Hall; 4 to 6, inclusive, form the Warsaw of the same author; while number 7 is the St.

Louis limestone reposing unconformably upon the brown massive layer number 6, and with the Coal Measures, number 8, superimposed unconformably upon it.

Warsaw Section.

	Feet.
6. Ash-colored brecciated limestone	25
5. Buff calcareous gritstone, fossiliferous	8
4. Blue clay-shale with thin bands of impure limestone	25
3. Compact buff limestone with encrinital layer above	6
2. Blue clay-shales; "geode-bed"	30
1. Thinly bedded encrinital limestone, highly fossiliferous; exposed	15

Numbers 1 to 5 are regarded as Keokuk. Of these numbers 3, 4 and 5 are the typical Warsaw of Hall. Number 6 belongs to the St. Louis.

Louisiana Exposures.

	Feet.
15. Soil	2
14. Compact yet thinly bedded encrinital limestone, with considerable gray and brown chert	50
13. Massive, white encrinital limestone, coarse grained	12
12. Brown encrinital limestone with irregular chert bands and thin clay seams occasionally	20
11. Very heavily bedded white encrinital limestone	11
10. Brown encrinital limestone, somewhat sandy in places; earthy and disintegrating on exposure to the weather	15
9. Fine grained buff limestone	15
8. Brown sandy shales	12
7. Green clay-shales	60
6. Thinly bedded compact buff limestone, in layers from 4 to 6 inches in thickness, with a thin and sandy highly fossiliferous seam at the base	50
5. Blue clay-shales	2
4. Black fissile shale	4
3. Compact, massive buff limestone	10
2. Gray oolitic limestone	5
1. Blue clayey shales with numerous thin limestone bands, rich in fossils; exposed	60

All above number 9 belongs to the Burlington limestone, and the beds from numbers 6 to 9, inclusive, to the Kinderhook. Number 9 is the Chouteau limestone of Swallow; numbers 7 and 8 the Vermicular sandstone and shales of the same author; and number 5 is the Lithographic limestone.

St. Louis Section.

	Feet.
Blue and gray limestone, compact, rather heavily bedded, more or less highly fossiliferous, with thin marly partings; exposed to water level	125

*Ste. Genevieve to Ste. Mary.**

	Feet.
8. Soil	3
7. Soft, yellow ferruginous sandstone, exposed	15
6. Clay-shales and heavily bedded blue limestone	125
5. Yellowish sandstone (Aux Vases river)	70
4. Bluish thinly bedded limestone (Ste. Genevieve)	45
3. Rather heavily bedded blue and ash-colored limestone with marly partings, showing cross-bedding in places; oolitic and cherty locally	135
2. White oolite, fossiliferous	15
1. Massive, compact limestone, white in color and highly fossiliferous; exposed	50

Number 1 is probably upper Keokuk. Numbers 2 to 4 belong to the St. Louis group; while number 6 is the Kaskaskia. Number 7 is the basal sandstone of the Coal Measures.

Chester Section.

	Feet.
8. Furruginous sandstone with plant remains; exposed	25
7. Green and blue clayey shales with occasional limestone bands	10
6. Gray limestone, more or less nodular and impure	45
5. Green and blue clayey shales with thin limestone layers, highly fossiliferous in places	45
4. Heavily bedded, compact encrinital limestone with clay partings	3
3. Drab fossiliferous shales with thin calcareous seams	4
2. Dark drab compact limestone	4
1. Heavily bedded blue and gray limestone; above water level	75

THE KINDERHOOK BEDS.

Definition.—There seems to be a general unanimity of opinion as to the propriety of regarding as a distinct subdivision the lower Carboniferous rocks of the Mississippi basin below the Burlington limestone. The upper line of demarkation is easily recognizable throughout its geographic extent. Its lower limit, however, has not been made out satisfactorily over the entire area of its occurrence; but in many places the group of strata is known to rest on the "black shale" so well developed in Tennessee and generally regarded as Devonian in age. For the group of beds in question, or parts of the group, various names have been given. But their historical consideration need not be dwelt upon at length here. Whatever may be eventually the most appropriate term to apply to this section, it seems advisable for the present to retain Meek and Worthen's name for these rocks as exposed along the line of the Mississippi river.

*The sections of Ste. Genevieve, Chester and Louisiana are from personal notes made in connection with the geological survey of Missouri and are incorporated in this place by the kind permission of the state geologist, Mr. Arthur Winslow.

Among the earliest references to the rocks of this group in the continental interior is made in connection with Owen's explorations in southeastern Iowa.* This author called some sixty feet of ash-colored shales, exposed above the level of the water in the Mississippi river to the base of the encrinital limestone at Burlington, the "argillo-calcareous group," and regarded them as belonging to the lower part of the Subcarboniferous. These shales were actually a portion of the median member of what Swallow,† in Missouri, termed the "Chemung" group. This group was divided into (1) the Chouteau limestone, (2) the Vermicular sandstone and shales, and (3) the Lithographic limestone. Within the limits of the region under consideration these three divisions are quite persistent and easily recognizable over a wide area. For present convenience the last two members may be termed more appropriately the Hannibal shales and the Louisiana limestone respectively, since at these places in eastern Missouri they are exposed in their full development.

Throughout Iowa, Illinois and Missouri, at least, and perhaps in other states also, wherever the Kinderhook rocks are exposed, its members, as here designated, will always be recognized to a greater or less extent, particularly in faunal studies. Over all the three states named these subdivisions are sharply defined lithologically, except possibly toward the northern known limits, though there these rocks have received very little or no attention. At the present time it seems very probable that the third or lowest member—the Louisiana or Lithographic limestone—will find a closer relationship with the Devonian than with the Carboniferous, and that eventually it will be regarded as the capping stratum of the former over all the territory contiguous to the Mississippi.

In 1858 Hall still continued to regard the Burlington, Iowa, section below the oolite layer as Chemung. But he also included in the group some yellow sandstones occurring fifty miles to the northward, which Calvin ‡ has recently proved conclusively to be of Devonian age.

Although Owen had referred the shales lying immediately below the limestone at Burlington, Iowa, to the Subcarboniferous more than a decade previously, Meek and Worthen,§ in 1861, were the first to prove beyond a doubt that the faunas of the rocks along the Mississippi river between Burlington and St. Louis and lying between the "black shale" and the Burlington limestone have much closer affinities with those of the overlying strata than with those below, and therefore that the rocks in question properly belong to the lower Carboniferous series. The name "Kinderhook" was then proposed for the formation.

---

*Geol. Sur. Wisconsin, Iowa and Minnesota, 1852, p. 92.

†Ann. Rep. Geol. Sur. Missouri, 1855, p. 103.

‡Am. Geol., vol. iii, 1889, p. 25.

§Am. Jour. Sci., 2d series, vol. xxxii, p. 228.

Soon afterward Worthen* published further details, especially in regard to the typical locality, Kinderhook, Illinois. Various sections in the neighborhood were fully described, leaving no doubt as to the real limits that were intended to be assigned to the terrane. On the opposite side of the river, in Missouri, the exposures are almost continuous for more than thirty miles and show well the relations from the "black shale" to the upper division of the Burlington limestone.

In the Iowa section White† recognized as Kinderhook the Burlington rocks previously called Chemung, together with a few feet of what was once considered as belonging to the superimposed stratum.

The "Chouteau" group takes its name from the leading member of this three-fold division, the Chouteau limestone. The application in this sense was first made by Broadhead,‡ who used the term to cover the same limits as Swallow's "Chemung" in the earlier Missouri reports. Very recently the name apparently has been extended by Williams § to embrace the lower Carboniferous littoral deposits (Waverly grits, etc) and the open sea deposits of argillaceous and calcareous material (Kinderhook shales and limestones).

From the foregoing it appears that in the states bordering the Mississippi river the term Kinderhook has priority in the naming of the lower member of the lower Carboniferous as now generally understood. Whether or not Waverly or Marshall, as the rocks of probably the same age in Ohio and Michigan are called, should replace Meek and Worthen's name remains to be seen. These were probably littoral deposits. Both lithologically and faunally they are sufficiently distinct from the more western deposits to make a separate designation desirable.

Louisiana Limestone.—Swallow's Lithographic limestone is exposed best perhaps at Louisiana, in Pike county, Missouri, where it attains a maximum thickness of more than 60 feet. As its early name suggests, its texture is very similar to that of the stones used in lithography; but this peculiarity does not extend throughout its entire range. It is usually rather thinly bedded, the layers being from four to six inches in thickness, and wherever exposed stands in high, mural escarpments, with every appearance of artificial masonry. The lower layers are more or less arenaceous, and yield numerous fossils. At Louisiana this limestone rests on a dark clayey shale, whose thickness is about six feet, and this again on a compact, buff, magnesian limerock, probably of Silurian age.

Hannibal Shales.—The Hannibal shales (Vermicular shales of Swallow) have a maximum thickness of about 75 feet at the typical locality. In

*Geol. Sur. Illinois, vol. i, 1866, p. 108.
†Geology of Iowa, vol. i, 1870, p. 192.
‡Geol. Sur. Missouri, 1871, p. 26.
§ Bul. U. S. Geol. Sur., no. 80, 1891, p. 169

Missouri the upper portion is sandy in places and forms often a rather compact, shaly sandstone, becoming harder northward, where it assumes the character of a substantial sandrock. The latter is apparently entirely absent in the southwestern part of the state. Downward, the shaly sandstone rapidly looses its arenaceous character and passes quickly into bluish or greenish clay-shales which appear remarkably uniform over broad areas. At Burlington, Iowa, recent excavations show a thickness of more than 70 feet, while borings indicate a thickness of double that figure. Toward its known limit southward, in Greene county, Missouri, for example, more than 50 feet of these shales have been observed, and there is every reason to believe that they are considerably thicker.

It is commonly supposed that these shales are destitute of fossils, but late excavations at various places have disclosed rich faunas of a most interesting and instructive nature.

Chouteau Limestone.—The upper member of the Kinderhook is a fine grained, compact limestone, buff in color, and usually more or less impure from an admixture of clayey material. At Hannibal and Louisiana it has a thickness of from 10 to 15 feet, apparently thinning out rapidly northward. It is probably represented at Burlington, Iowa, by a few feet of buff calcareous layers lying at the base of the great limestone at that place. At Legrand, in Marshall county, Iowa, the 50 feet of buff magnesian limestone immediately underlying the Burlington may, perhaps, be a northward extension of the Chouteau. Southward in Missouri the bed in question increases in thickness until it attains a measurement of 100 feet or more at Sedalia, and about 50 feet in the vicinity of Springfield in the southwestern part of the state. Near Ste. Genevieve there are probably from 75 to 100 feet of this limestone. It is quite possible that in the northwestern part of this state, far below the Coal Measures, this limestone attains even a much greater thickness.

Osage Limestones.

Definition and general Relations.—From a purely paleontological standpoint, the advisability of including the Burlington and Keokuk limestones under a single name was pointed* out several years ago. For this long needed term Williams† has proposed "Osage."

Owen's encrinital limestone embraced practically the same beds that were afterwards called the Burlington; and his lower Archimedes corresponded to Hall's Keokuk group below the geode bed. Shumard seems to have used the term "Encrinital limestone" in a variety of

* Am. Journ. Sci., 3d series, vol. xxxviii, 1889, pp. 186–193.

† Bull. U. S. Geol. Sur., no. 80, 1891, p. 169.

senses—sometimes referring to the Burlington alone, sometimes to both Burlington and Keokuk, and often to the Burlington and a part of the Keokuk. Partly on lithological grounds, but chiefly for paleontological reasons, the "Osage" may be regarded as made up of three members—upper, middle and lower—coinciding essentially with the Keokuk and the upper and lower Burlington limestones. In regard to the fossils of the three horizons, the most conspicuous differences are found among the crinoids, which form such a characteristic feature of the several faunas. These general differences were first suggested by White,* and quite recently † they have received further attention. They may be restated briefly here: Those species from the lower Burlington are of small size, delicately constructed and highly ornamented. In the upper division of the Burlington the peculiar delicacy pervading the forms of the lower bed is absent or has assumed a ruder character, while in the Keokuk the crinoids are characterized by large size, rough and massive construction, bold and rugged ornamentation, and a conspicuous exaggeration in many structural details. The last consideration is of great interest, since it appears that in general the exaggeration of anatomical features is indicative of important biologic changes in that particular zoological group in which such extreme developments take place.

It is apparent from a close study of the crinoids (and in a somewhat less marked degree among other zoological groups) that there was an abrupt change of physical conditions at the close of the Keokuk epoch. One-half of the Carboniferous genera had become extinct; the great group Camerata had passed away, with the exception of the Hexacrinidæ and a few depauperate forms of several other genera whose existence was quickly brought to a close. A large proportion of the genera in the extensive section Inadunata had disappeared; of those groups which survived to the close of the period, a diminutive species was the sole representative of the Larviformia, while of the great group of the Fistulata only the typical genus (including several subgenera) of the Poteriocrinidæ extended through the entire lower Carboniferous.

As already stated in another place, the sudden extinction of a large proportion of the crinoidal and other forms of life at the close of the Keokuk is certainly suggestive of a series of wide-spread changes in the geographic and bathymetric extent of the great interior sea; and there is sufficient evidence to indicate that at the close of the Keokuk and during the early part of the so-called Warsaw the northern coast line of the broad shallow gulf moved rapidly southward, and that this movement was soon followed by a slight depression. The St. Louis waters then pushed northward again, in some places several hundred miles.

* Journ. Boston Soc. Nat. Hist., vol. vii, pp. 224, 225.

† Keyes: Am. Journ. Sci., 3d series, vol. xxxviii, 1889, pp. 191, 192.

Burlington Limestone.—The lithological characters of the Burlington are remarkably constant over broad stretches of territory, and they are practically identical over its entire extent, so far as it has been traced accurately, from northern-central Iowa to western Illinois, southwestern Missouri and Arkansas. Everywhere it is the same coarse grained encrinital limestone, intensely white and quite pure in certain layers. For the most part its geographic distribution is west of the Mississippi river. East of the stream the typical exposures of this rock are unimportant and unknown beyond the immediate vicinity of the great watercourse.

Keokuk Limestone.—The upper member of the Osage, on the other hand, has its distribution chiefly on the eastern side of the "Father of Waters," covering a wide area in Illinois, Indiana, Kentucky and Tennessee. West of the river the most typical exposures are in southeastern Iowa and northeastern Missouri. At Boonville, in central Missouri, where these rocks have been reported, the faunas contained do not indicate the true Keokuk. In the southwestern part of the same state no typical Keokuk has been observed, so far as is known. The encrinital limestone of that region, which has been thought by some to represent both the Keokuk and Burlington limestones of the more northern localities, appears to be the latter alone. Extensive collections of fossils made in various parts of the formation show few species that can be regarded as belonging to the true Keokuk. This is all the more remarkable from the fact that a vertical section of the Kinderhook and Burlington beds of the region is essentially identical, lithologically, with the one of northeastern Missouri. After all, the upper member may be present, for the recent personal observations were not conclusive enough to preclude its existence entirely.

There is, however, another very suggestive consideration bearing upon the relations of the Keokuk and Burlington limestones which is worthy of notice. It was strongly impressed some years ago while engaged in a study of the Carboniferous echinoderms of the Mississippi basin. According to this inference it appears that the lower portions of the Keokuk and Burlington rocks were deposited nearly at the same time but in practically separate basins, the barrier being approximately along the line of the present Mississippi river. As the obstruction was gradually removed, the animal forms of the two districts mingled more or less completely, and those of the eastern area being better adapted to the changing conditions displaced the old occupants of the eastern portion of the Burlington territory as the sea became gradually deeper, eventually replacing them altogether; so that in the area of the typical localities of these rocks a succession of faunas is represented that is not shown elsewhere. Thus the so-called Keokuk overlapped, by degrees, the Burlington, and while the fauna of the upper Keokuk was living where portions of Iowa and

Missouri are now limited, the lower Burlington forms still flourished in the waters to the southwestward, even as far as the present boundaries of New Mexico.

In regard to the derivation of the Keokuk fauna from the areas considerably east of the Mississippi river line and of the Burlington from districts west of that limit, a further hint is obtained in an examination of the various faunas that immediately preceded. Again the crinoids may come into service. Attention already has been called to the peculiarly fitting role that the stemmed echinoderms play in considerations of this kind, and to their ornamentation and general structural characters as shown in the three members of the Osage. Composed of regular plates, definitely arranged and often highly ornamented, delicate pinnulated arms, and characteristic stems, these organisms were admirably adapted for recording the changes in the physical conditions of their environment. The species of the Devonian and the early Carboniferous in the eastern portion of the Mississippi basin were, with few exceptions, large, massive, heavily plated forms, coarsely ornamented, and possessing in many cases a peculiar extravagance of structure. An examination of the species from the Kinderhook and the accessible Devonian of the western district shows that in great part the forms were all highly and delicately sculptured, rather frail in construction, and of small size. There seems to be but little doubt that in the district of southeastern Iowa the Burlington forms are genetically related to those of the subjacent deposits. The relationships of the same forms to those of the rocks immediately above has always appeared to be only in part genetic. The apparently direct succession is explicable in many cases on the assumption (which is very probable) that the barrier alluded to above was only partial, allowing a certain amount of mingling. The lithological characters of the strata immediately beneath the Burlington also attest the shallowness of the water along the line mentioned.

Warsaw Beds.—The Warsaw beds, as defined by Hall * and as exposed at the village of Warsaw, Illinois, are composed of (1) 10 feet of compact, buff-colored limestone, (2) 30 feet of blue calcareous shales with many thin limestone seams, and (3) 8 feet of yellow arenaceous limestone. At Keokuk, five miles above, all three layers are thinner, and at neighboring places they exhibit still different characters. Southward the beds lose their argillaceous nature and appear not to be separable from the associated limestones. These layers, together with the geode bed, which is usually considered the upper member of the Keokuk, may be regarded as mere local developments to which little importance is to be attached. In a quarry a short distance northwest of Rand park, at Keokuk, Iowa,

* Geology of Iowa, pt. i, 1858, p. 97.

there is a good exposure showing the upper surface of the buff arenaceous limestone to be water-worn and weathered; and directly upon the eroded rock rests 20 feet of brecciated limestone. Whether or not this point can be regarded as a portion of an ancient land surface older than the St. Louis limestone depends partly upon the results of further investigation and partly upon the final decision as to the origin of the brecciated rock.

At Hall's typical locality it is manifest that the Warsaw beds are properly the superior portion of the Keokuk limestone. This inference is directly derivable both from the faunal and stratigraphical features, and in a less marked degree from the lithological nature of the deposits. The layers passing under this name reported from other localities are now known to have various relationships with the overlying and underlying strata. Alleged faunal peculiarities have usually been the chief grounds for considering the Warsaw as a distinct subdivision of the lower Carboniferous. Most writers on the subject have united the beds under discussion with the St. Louis; a few with the Keokuk. This difference of opinion has arisen largely from assumptions made at the places most thoroughly studied by the respective authors, without due allowance being made for the varying conditions in separated localities. A careful comparison of notes and a somewhat extended study in the field show that the term "Warsaw" has been loosely applied since its original appearance as a geological name. In the majority of places the so-called Warsaw is clearly the lower part of the St. Louis limestone. Thus the investigators above alluded to were perfectly correct in contending that the "Warsaw," as they understood it, was really a portion of the St. Louis. But they made the mistake of claiming that the Warsaw of all localities is St. Louis. It is apparent, then, that in some places the so-called Warsaw cannot be separated from the St. Louis limestone; in others it is best united with the Keokuk. It seems better, therefore, to drop the term in its application to a distinct section of the lower Carboniferous, or Mississipian series, with a rank equal to the other subdivisions here recognized.

St. Louis Limestones.

Since first recognized by Shumard, little difficulty has been encountered in locating the St. Louis limestone over a wide stretch of country. Its northern border is several hundred miles beyond any known exposure of Keokuk rocks. From this limit nearly to the Missouri river the limestone is quite thin; but south of the latter point it rapidly thickens, until in Ste. Genevieve county, Missouri, it attains a measurement of more than 300 feet, and still farther southeastward more than double the thick-

ness known in the state mentioned. The Ste. Genevieve limestone, which Shumard differentiated from the St. Louis deposits near the mouth of Aux Vases river, a few miles below the old village of Ste. Genevieve, appears to be merely the upper part of the main group of strata; and the fossils contained fully substantiate this view.

The unconformity of the St. Louis rocks upon the underlying strata in Iowa and the adjoining portions of the neighboring states has been fully explained by White.* The thinness of the limestone has been alluded to already. This is due partly to the thinning out of the strata northward and partly to the subaërial erosion prior to the deposition of the Coal Measures of the region.

Toward its present northern limits the upper part of the St. Louis is composed of soft, plastic, highly fossiliferous marls, which are well exposed at Fort Dodge, in the northern-central part of Iowa, and at Harvey, in the central portion of the state, besides numerous other localities immediately to the southward of the last named place. At Elk cliff, a few miles from Harvey, as well as elsewhere, the marl has been removed entirely down to the hard limestone upon which rests directly the strata of the Coal Measures. Nor is this all: the uneven configuration of the ancient land surface is further shown by the presence of more than 100 feet of clays and shales, represented a short distance down the stream (Des Moines river), before the level of the summit of the old limestone elevation is reached.†

Over all the northern area of the St. Louis a characteristic brecciated rock is observable. But south of the Missouri river evenly bedded limestones are present, with occasional extensive beds of oolite. In places at Ste. Genevieve the oolitic limestones present perfect cross-bedding, such as is commonly seen in sandstones, a fact which is very suggestive in its bearing upon the origin of certain oolites.

The faunal features of the St. Louis are peculiar in many respects, and quite distinct from those of both the overlying and underlying strata, particularly from the latter.

Kaskaskia or "Chester" Beds.

Aux Vases Sandstone.—In southern Illinois and southeastern Missouri the Kaskaskia comprises extensive beds of limestone and shale. Everywhere over this district these calcareous portions, which greatly predominate in the lower part of the group, are underlain by a fine grained ferruginous sandrock. This sandstone is recognizable above the city of St.

* Geology of Iowa, vol. i, 1870, pp. 225-229.

† Keyes: Bul. Geol. Soc. Am., vol. 2, 1890, p. 287.

Louis, where it is a dozen feet or more in thickness; southward it rapidly thickens until in the vicinity of the typical locality it attains a maximum measurement of more than 100 feet.

The true significance of this great sandstone separating the St. Louis and Kaskaskia limestones does not appear heretofore to have been understood fully, especially when taken in connection with the absence of Kaskaskia rocks north of the Missouri river. Here is an extension of limestone—the St. Louis—that before the Coal Measures were laid down was greatly eroded over a large part of its area, and over another adjoining portion having a great sandstone superimposed. This would seem to indicate that the broad expanse of waters which, during the deposition of the St. Louis beds, reached nearly to the present northern boundaries of Iowa had retreated more than 400 miles to the southward. Dry land existed over a large part of the area formerly covered by the St. Louis waters, and bordering this continental mass arenaceous deposits were laid down in the shallow littoral waters.

In all the Carboniferous of the Mississippi basin no group of strata appears to form a better defined natural geological unit than those beds commonly passing under the name of Kaskaskia or Chester.

The great arenaceous deposit lying at the base of the Kaskaskia limestone has been termed the "ferruginous sandstone" by Shumard and others. Many observers, however, have confounded it with a lithologically similar sandrock situated at the base of the Coal Measures and consequently located on, instead of under, the Kaskaskia. For convenience in reference and in order to avoid further confusion this great sandstone will be called here the *Aux Vases sandstone*, from the river of that name in Ste. Genevieve county, Missouri, on which the rock is exposed. Of course in northern Missouri and Iowa, where the superior member of the Mississippian series is wanting, the basal sandrock of the Coal Measures occupies the same stratigraphical position as the lower Kaskaskia sandstone—that is, superimposed upon the St. Louis.

Kaskaskia Limestone and Shales.—Everywhere over that part of the upper Mississippi valley in which the Kaskaskia is absent the St. Louis rocks, as already stated, are weathered and deeply channeled, many gorges passing downward even to the Keokuk, thus showing pretty conclusively that these portions of the territory were actually above sea level during a part of the Kaskaskia deposition. That the northern shore-line continued to move southward after the Kaskaskia epoch had begun, and perhaps even until the latter half of the interval had set in, is shown by the successive attenuation of the several beds and by the deeply excavated ravines, where soon afterward were laid down the local sandstones and shales of the Coal Measures. In a number of cases, at least, these hardened

sand accumulations, lying in narrow gorges, have been regarded erroneously as local depositions of Kaskaskia grit intercalated in the shales and limestones. Futhermore, these consolidated sands contain plant remains, and inasmuch as they have been considered as parts of the Kaskaskia, it is quite probable that this will account for some of the reported discoveries of terrestrial floras in the rocks of the Mississippian series.

Faunally, and especially stratigraphically, the Kaskaskia, as displayed everywhere over a broad area adjacent to the line of the principal section, appears separated from the St. Louis far more widely than any other two members of the entire Carboniferous in the continental interior.

The term "Chester" has been used by some authors for the beds here designated as Kaskaskian. There seems to be, however, but little doubt that the latter name was published some years before Chester made its appearance in print. To be sure, Worthen, while an assistant of Norwood on the geological survey of Illinois, did suggest, orally or in his manuscript notes, the name "Chester" for the beds in question as early as 1853; but the name was known for several years only to members of Norwood's corps, as Worthen himself says.* It was at least a dozen years later before the term was published with definite stratigraphical significance, and then with the full knowledge that it covered the same ground as Hall's "Kaskaskia." Hall, as early as 1856, read a paper before the Albany Institute, in which he proposed a classification of the lower Carboniferous of the Mississippi basin; and two years later he published essentially the same scheme in his Iowa report,† accompanied by a clear description of this formation. Kaskaskia necessarily must be retained, therefore, for the upper member of the Mississippian series in preference to "Chester." If it is desirable to keep the latter term in geological nomenclature, it might be advisable to restrict it to the upper shaly division, which can advantageously be distinguished from the lower massive limestones, and "Chester shales," as they are now often called locally, could still be made a useful term.

Coal Measures.

Along the line of the general section the Coal Measures occupy an unimportant place. The exposures are chiefly of the basal sandstone and the associated shales which outcrop along the river only at long intervals in old gorges and superimposed upon members of Mississippian series. As already intimated, the St. Louis limestone above the mouth of the Missouri, and a goodly proportion of the Kaskaskia below

*Geol. Sur. Illinois, vol. i, 1866, p. 11.

†Geol. Iowa, pt. i, 1858, p. 109.

hat stream, have been land surfaces and were greatly eroded before the invasion of the coal swamps. In many places throughout the same region the coal strata rest on older rocks, on other members of the Mississippian series, and even on the Devonian.

Further consideration of the series is unnecessary here. In one portion of the area under consideration the Coal Measures have been studied with considerable care and a very detailed section made from near the ancient land limit seaward a distance of nearly 75 miles. A preliminary statement of these observations has been made elsewhere.*

Recapitulation.

From the foregoing description it is to be inferred that, on the best lithological, stratigraphical and faunal evidence now at hand, the Mississippian series embraces four groups, which may be tabulated as follows:

Mississippian series	Kaskaskia group	"Chester shales."†
		"Kaskaskia limestone."
		Aux Vases sandstone.
	St. Louis group	"Ste. Genevieve limestone."
		St. Louis limestone.
		Warsaw limestone (in part; not typical).
	Osage group	Warsaw shales and limestone (typical).
		"Geode bed."
		Keokuk limestone.
		Upper Burlington limestone.
		Lower Burlington limestone.
	Kinderhook group	Chouteau limestone.
		Hannibal shales.
		Louisiana limestone.

The "Louisiana limestone" is layer number 6 of the Louisiana exposures. The "Hannibal shales" comprise numbers 7 and 8 of the same locality; probably also numbers 1 and 2 of the Burlington section. The "Chouteau" is number 9 of the Louisiana limestones. The "lower Burlington limestone" embraces numbers 7 and 8 of the Burlington section; the "upper Burlington limestone" numbers 9 and 10 of the

* Bull. Geol. Soc. Am., vol 2, 1890, pp. 277–292, plates ix, x.

† The names in quotation marks are local applications. The Kaskaskia, aside from the basal sandstone, appears to be a well defined two-fold division, and it seems advisable to keep the two members distinct, though special names are not retained for them here. The St Louis and Kaskaskia correspond essentially to Williams' "Ste. Genevieve group."

same. The two together form numbers 10 to 14, inclusive, at Louisiana. The "Keokuk limestone" is numbers 1 and 2 of the Keokuk exposures, number 1 of the Warsaw section, and probably number 1 of the Ste. Genevieve outcrops. The "geode bed" appears as number 3 at Keokuk and number 2 at Warsaw; the typical "Warsaw" embraces numbers 4 to 6 of the Keokuk section and numbers 3 to 5 at Warsaw. The "St. Louis limestone" is represented by number 7 at Keokuk, number 6 at Warsaw, all of the St. Louis section, and number 3 at Ste. Genevieve, while number 2 of the same section has been called the Warsaw limestone (not typical). The "Ste. Genevieve limestone" of Shumard is number 4 of the Ste. Genevieve-Ste. Mary outcrops. The "Aux Vases sandstone" forms bed number 5 between Ste. Genevieve and Ste. Mary, and underlies number 1 of the Chester section a few miles north of the town. The "Kaskaskia limestone" includes numbers 1 to 4 of the Chester section, and the "Chester shales" numbers 5 to 7 of the same section. The Coal Measures are represented at Keokuk by number 8, at Ste. Genevieve by number 7, and at Chester by number 8.

The great abundance of fossils in all the members of the Mississippian series of the interior basin makes the faunal test perhaps the most important of all in attempting a rational classification of the rocks of the region. Heretofore the remains of ancient life found in these rocks have been considered either from a purely biological point of view, or, in the majority of cases, from the standpoint of the mere species-maker; and it is only within the past few years that large numbers of species taken together have been compared with one another in order to marshal the confused collections into orderly arrangement, so that faunas may be studied as a whole.

The second important consideration to be taken into account in the present connection is the stratigraphical testimony. In the case of the Kaskaskia the physical breaks are unusually prominent, both above and below, over its entire extent in the upper Mississippi valley. What has just been said of the upper member of the series is equally true of the one immediately underlying, though in a less marked degree and over only a part of its superficial occurrence. Between the lower two groups the physical continuity is scarcely broken, and the separation is chiefly upon faunal and lithological grounds.

Lithologically the upper two members of the Mississippian are more alike than any of the others; yet as a rule they are readily distinguishable everywhere. The Osage group of limestones is over all its range encrinital, and stands out in marked contrast from the other three sections; while the lower subdivision is very different again, both in the calcareous and the argillaceous portions.

In regard to the minor subdivisions of the four groups above mentioned much might be said. The several sectional names proposed at various times have had wide values and, moreover, have been applied rather loosely.

In the Kaskaskia the upper shales and the lower limestones of Chester, Illinois, have been differentiated, while the Aux Vases sandstone has been placed at the base of the group, provisionally. It has not had, as yet, sufficient study over its entire exposure to satisfactorily consider its relationships in all its phases. Certain it is, however, that when the continental area north of the present city of St. Louis was being subjected to denudation prior to the deposition of the lower Coal Measures the great sandstone was laid down south of that point in the shallow littoral waters of the interior sea.

The St. Louis group has been divided into three limestone. Of these the Ste. Genevive has never come into general usage, and practically has been forgotten. The St. Louis limestone itself has been widely recognized, and in many places the lower portions have been correlated with the Warsaw beds as developed at the mouth of the Des Moines river.

The Osage group is now made to include all five of the hitherto recognized beds, the Warsaw proper, the geode layer, the Keokuk, and the upper and lower Burlington limestones.

The Kinderhook group is a three-fold division whose several members are strongly contrasted and persistent over wide areas.

The history of the shore-line shifting of the great interior sea is a theme for detailed elucidation. Much has already been done toward this end, but some further information is requisite before a satisfactory presentation of the subject can be made.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 301-330

TWO MONTANA COAL FIELDS

BY

WALTER HARVEY WEED

ROCHESTER
PUBLISHED BY THE SOCIETY
JUNE, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 301-330 JUNE 28, 1892

TWO MONTANA COAL FIELDS.

BY WALTER HARVEY WEED.

(Read before the Society December 30, 1891.)

CONTENTS.

1. THE GREAT FALLS COAL FIELD.

INTRODUCTION.

Near the rapidly growing city of Great Falls, Montana, the Missouri river emerges from the Belt mountains and begins its long eastward course through the great plains. The rapidly flowing stream soon con-

mences to cut through the nearly horizontal strata of the plains, and near Great Falls plunges over a series of sandstone ledges in a succession of cataracts collectively known as the "Great falls of the Missouri." Below the falls the sandstones gradually pass beneath the dark carbonaceous shales so well exposed at Fort Benton, from which place they take their name. These sandstones, with their interbedded shales, now known as the Great Falls formation, have long been known to all geologists visiting the region, but until recently failed to reveal any fossil remains and were referred to the Dakota epoch, whenever mentioned, on account of their inferior position to the well developed Fort Benton shales. Their true age was first made known by Professor J. S. Newberry,* who identified a number of fossil plants from the Great Falls formation and found

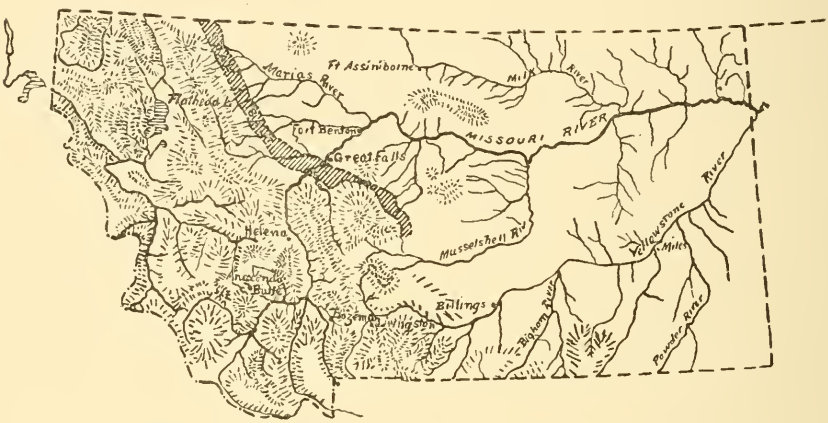


Figure 1.—*Sketch Map of Montana showing Location of Coal Fields.*

The shaded zone extending from the headwaters of Musselshell river to the international boundary includes the coal fields.

them to be species characteristic of the Kootanie rocks of the Canadian geologists.

South of Great Falls, a few miles nearer the mountains, this formation holds a thick seam of excellent bituminous coal, which is being extensively mined at Sandcoulée and has been opened at a number of other localities along the base of the mountains. The area underlain by coal has been called the Great Falls coal field, and as these strata constitute the only occurrence of the Kootanie rocks yet recognized in our territory they possess a decided interest apart from their economic importance.

In prosecuting a study of the coal fields of Montana for the United States Geological Survey, a visit was made to this field in the spring of

*School of Mines Quarterly, vol. viii, no. 4, July, 1887, p. 327.

1891, and the facts then observed are believed to be of sufficient interest to present to the Society. They prove—

1. The identity of the fossiliferous strata near Great Falls with those of the coal field;

2. The position of the formation relative to the Carboniferous and to the Fort Benton rocks, as established by a carefully measured detail section;

3. The occurrence of fresh-water shells above the coal;

4. The absence of recognizable Dakota strata;

5. The termination of the Carboniferous deposits in a series of shales and impure limestones, stratigraphically and lithologically the equivalent of the *Myacites* beds of the Jura-Trias of southern Montana, but carrying lower Carboniferous (Spergen hill) fossils.

The eastern portion of the field was examined by the geologists of the Northern Transcontinental Survey in 1889. Professor W. M. Davis, in studying the relation of the coal to the older rocks, measured two sections from the Cambrian to the horizon of the coal, of which detailed notes are not given. A graphic representation of these sections was published, with lists of fossils determined and an interesting account of the adjacent mountain region, in the reports of the Tenth census.*

In the investigation of the coals from an economic standpoint for the same survey, the coal seam was traced by G. H. Eldredge from the Judith basin to Belt creek, and sections of the seam, wherever opened at that time, will be found in his report.† Somewhat later Professor J. S. Newberry made an examination for the Great Northern railway of that part of the field now worked, and mentioned the general relations of the coal rocks to the underlying Paleozoic terranes, in a paper on the geology and botany of the country bordering the Northern Pacific railroad.‡

Location and Extent of the Field.

The Great Falls coal field, as already indicated, is situated at the base of the Rocky mountains in central Montana, and takes its name from the town to which it is tributary. Its proximity to Helena, the state capital, and to the great mining center Butte, with the increasing market afforded by the smelters and other industries of Great Falls itself, makes the field of the first importance in the future development of Montana.

Coal has been found in the Kootanie rocks all along the base of the mountains from the vicinity of fort Shaw eastward to the Judith basin.

* Tenth Census: Mining Industries, vol. xv, Washington, 1886, p. 697.

† Ibid., p. 739.

‡ Annals of the N. Y. Academy of Sciences, vol. iii, 1884, no. 8.

The seam has been opened at several places, and desultory working for the local supply has been attempted on St. Johns creek, west of the Missouri, and on Bird creek, Hound creek, Smith river, Dry Arrow creek, Willow creek, and Sage creek. The more extensive workings of Belt creek are sufficient to prove the value of the seam: the mines at Sandcoulée have an average daily output of 1,300 tons. It will be seen from the localities cited that the field embraces a strip of country a few miles in width, but extending along the base of the mountains for 125 miles, its extreme limits being yet undetermined (see figure 1).

Configuration and Structure.

Throughout its entire extent the coal field is an open, grassy plateau or prairie country, but rarely presenting low buttes or eminences left by the erosion of higher strata, and cut by numerous drainages whose coulées show sections of the rocks. To the southward the Belt mountains form a rugged range whose higher slopes are dark with a heavy growth of pines, the lower slopes presenting that park-like character that forms one of the chief charms of Rocky mountain scenery. The plateaus of the coal field extend northward, forming the western limit of the great plains. In the center of the field, Belt creek has cut a narrow valley whose groves of cottonwood and alders are in pleasant contrast to the monotonous grasslands of the plateaus. Belt butte, a conical hill of horizontal shales and sandstones, forms a conspicuous landmark, the girdle of sandrock about its slopes giving it the name. To the eastward the Highwood mountains break the continuity of the plains, rising abruptly as an isolated cluster of picturesque peaks. The drainage of the coal field, at least that part of it which was visited, is peculiar: The level plateaus are trenched by narrow coulées, which are frequently partially filled with drift and are now occupied by streams of relatively small size, streams that even in flood are not proportionate to the valleys they occupy. The evidence seems to show that a period of depression, when the plateaus were cut, was followed by a short time of relatively high elevation accompanying the advance of local glaciers and a vigorous drainage, which was followed in turn by the present period of scanty precipitation.

The abundance of glacial drift on the plateaus was noted by Professor Newberry. It is conspicuous when the glacial gravels fill pre-existing hollows and drainage channels, but on the mesas forms but a thin and widely spread mantle in which the bowlders are seldom of large size. The material points to local origin of the drift, coming from the Little Belt range. In the coal field proper no true moraines were observed.

The gently inclined strata of the Great Falls coal field rest conformably upon the Paleozoic terranes flanking the granitic axis of the Belt mountains, the easternmost range of the Rocky mountain cordillera of this locality. In these steeply upturned and folded Paleozoic strata the Cambrian, Silurian, Devonian and Carboniferous rocks have been recognized by means of fossils. The massive white limestones of the Carboniferous form the foothill country and pass beneath a series of gypsiferous red sands and limy shales long thought to represent the Jura-Trias but recently found to contain Carboniferous fossils, and these are in turn overlain by the sandstones and shale belts of the Great Falls formation. To the northward these coal rocks are in turn covered by a heavy series of strata that pass into typical Fort Benton beds as identified by Professor Newberry.*

The Highwood mountains, whose proximity to the chains formed by the uplifts of the eastern Cordillera would suggest a similar origin, are really a remnant of still higher Cretaceous beds, preserved during the erosion of the surrounding country by a network of dikes and sheets whose injection produced an induration of the strata that has left them as a record of the sediments once covering this part of the plains. Toward the east and west this same general structure, with local modifications, continues along the base of the Rocky mountains.

The geological Column.

Sections.—The entire geological column, from Archean gneiss to the shales of the Fort Benton group, is well exposed along the course of Belt creek. This stream, rising in the Belt mountains, flows for several miles westward along the strike of the Paleozoic limestones, and then turning northward has cut the picturesque Sluice-box canyon through massive Paleozoic beds, and reaches the more readily eroded clays and sandstones of the Mesozoic. At the lower end of Sluice-box canyon, near Riceville, the Paleozoic limestones dip deeply northward beneath the arenaceous beds of the Gypsum series and the overlying gray shales. Starting at this point, a continuous section was measured from the massive mountain limestones of the Carboniferous to the beds of supposed Fort Benton age which overlie the coal-bearing strata and form Belt butte. These measurements are given in the natural order.

The following table shows, in considerable detail, the section (represented graphically in figure 2) exposed in Belt butte:

*School of Mines Quarterly, vol. viii, 1887, p. 327.

Belt Butte Section.

			Feet.
26.	Sandstone, gray, slaty and hard, forming cap of the butte		80
25.	Slate, black		20
24.	Limestone, white and hard; forms upper "belt"		20
23.	Sandstone, gray, irregularly bedded, breaks into shelly detritus		90
22.	Shale, black and earthy		100
21.	Sandstone, unevenly and thinly bedded, usually light earthy brown, holding carbonaceous layers of 1 to 3 inches; principal "belt" of the butte		50
20.	Sandy shales, black and iron-stained but hard and shelly		20
	Sandy shales, gray, more arenaceous than those beneath		40
	Sandy shales, fissile and carrying ½ proportion black shale; facies decidedly Benton		25
	Shale, black		75
	Shale, sandy, gray, breaking into cubical bits		50
	Limestone		10
	No good exposures, but slopes show débris of white vitreous quartzite resembling novaculite		75
19.	Shale, black and earthy		10
	Sandstone, marked by fucoidal rolls		½
	Shale, black and earthy, with one 6-inch band of sandstone		25
	Sandstone		2
	Shales, red and purple to purple-black, with rare layers of harder sandy rock whose splinters strew slopes		140
18.	Sandstone, gray, weathering light brown; forms top of a broad bench extending back to the base of Belt butte		20
17.	Gasteropod bed; *Goniabasis*, *Neritina*, *Corbula* (?)		10
	Sandstone, dense, lilac-colored, weathering purple-brown		10
16.	Series of thinly bedded sandstones and limestones with alternating beds of shale, well exposed in coulée, but not of sufficient interest to warrant more detailed section, viz:		160
	k. No exposure	21	
	j. Sandstone, gray, cross-bedded	10	
	i. Shale		
	h. Sandstone, buff, dense, uniform		
	g. Sandy lilac-colored ledge	2	
	f. Sandstone	5	
	e. Lilac-tinted freestone	20	
	d. Sandstone, fissile, gray, quartzose, very hard and iron stained	17	
	c. Ledge of pink and lilac rock	30	
	b. Red and gray sandstones and shales	45	
	a. Shale, sandy, buff, with red blotches	10	
15.	Sandstone ledge, prominent stratum that throughout the valley lies over coal		50
14.	Coal		10
			1,092½

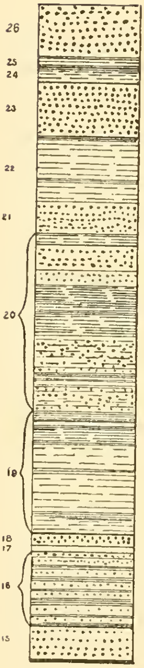


FIGURE 2.—*Section at Belt Butte.*

The Belt butte section is supplemented by that exposed on Belt creek, which comprises the following sequence (represented graphically in figure 3):

Belt Creek Section.

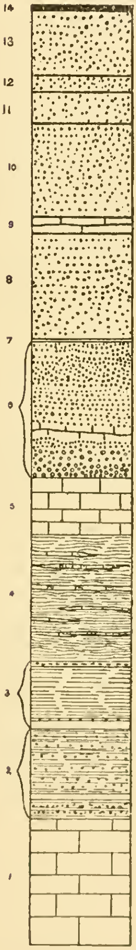


FIGURE 3.—*Section on Belt Creek.*

			Feet.
	Overlying beds of Belt butte section		1,192½
14.	Coal		10
13.	Shaly sandstones		100
12.	Sandstone belt		25
11.	Shales, limy		50
10.	Sandstones, white		150
9.	Limestone, gray and red, rusty		25
8.	Sandstone, white		5
	Sandy shales, the lower 40 feet very ferruginous and brown		95
	Sandstone, white, cross-bedded; forms persistent ledge		6
	Sandstone, shaly and iron stained		10
	Sandstone; ledge forming bluff		50
7.	Limestone, dense, light earthy gray		5
6.	Conglomerate and sandstone, Jurassic fossils		215
5.	Limestone, white, red earthy patches, Paleozoic facies		90
4.	Otter Creek shales; alternating gray, purple, green and black shales and earthy limestones yielding Carboniferous fossils; comprising—		212
	x. Shales, dark gray and black alternating with purple and green	45	
	w. Limestone	5	
	v. Shale, gray	30	
	u. Limestone, white	3	
	t. Shales, green and purple, limestone lenses	25	
	s. Limestone, white, conchoidal fracture	6	
	r. Shale, gray, green and red	8	
	q. Limestone, hard, dense, purplish-brown	1½	
	p. Shale	1½	
	o. Limestone, pebbly, containing gasteropod shells	2	
	n. Shale, gray	3	
	m. Limestone, gray, weathering creamy, usually brecciated	2	
	l. Shales, carrying *Rhynchonella*, etc.	15	
	k. Limestone, irregularly bedded and of varying tints of gray	5	
	j. Shale, black and earthy	½	
	i. Limestone	15	
	h. Shale, earthy dark gray	8	
	g. Limestone, soft, crystalline	3	
	f. Shale, purple-gray	8	
	e. Limestone	3	
	d. Shale, black	16	
	c. Gypsum	2½	
	b. Limestone conglomerate	2	
	a. Shale, dark gray	2	
3.	Black chert belt		8
	Limestones and shales		80
	Gypsum		3
	Sands, gray and white		12

			Feet.
2.	Red sands and gypsum layers made up as follows:		
	f. Sands, red	10	
	e. Gypsum, pure	5	
	d. Sands, green-gray, shaly	35	
	c. Gypsum, impure	$1\frac{1}{2}$	$101\frac{1}{2}$
	b. Sands, reddish, soft, 3 belts of gypsum, 3 to 6 inches	25	
	a. Sands, crumbling, red and white or gray	25	
	Limestones, granular, earthy		$7\frac{1}{2}$
	Sandy clays, red and green mottled		30
1.	Carboniferous limestones*		200
			$2,572\frac{1}{2}$

The Carboniferous.—The series of red sandy gypsiferous beds overlying the massive limestones of the Carboniferous and so closely resembling the "Triassic" red beds were diligently searched for any traces of fossil remains, but without success. This series (number 2 of the section) consists of crumbling sands, soft and often incoherent, generally red in color, though also white and gray, containing numerous seams or beds of gypsum. The series corresponds in position and general characters to the "red beds" which overlie the Carboniferous in Wyoming.

Overlying these gypsiferous red sands, there is commonly seen a series of gray beds, also characterized in this section by layers of gypsum, one of which is 3 feet in thickness. The gray shales and earthy limestones of this series (number 3 of the tabular section) is capped by a belt of black chert 8 feet thick, which was found at this horizon in several parts of the field. The earthy limestones and shales resemble the Jurassic of southern Montana, but are barren of fossils.

The series of alternating red or purple and gray shales and limestones (number 4 of the section) are characterized by abundant fossil remains. The thin beds of limestone, often but a few inches in thickness, contain a number of small serpulas and the shales contain a variety of fossils. These fossils have been seen by Dr. C. A. White and unhesitatingly referred to the Carboniferous age. They have been identified by Mr. C. D. Walcott, who reports the following species, viz, *Retzia verneuiliana*, Hall; *Rhynchonella osagensis*, Swallow; *Athyris subtilita*, Hall; *Bellerophon carbonarius*, Cox; also lamellibranch shells belonging to the genera *Allorisma*, *Schizodus*, and *Aviculopecten;* as well as two species of *Fenestella*, shown on thin fragments, and two species of coral of the genera *Chætetes* and *Lophophyllum* (?). Mr. Walcott reports that "the species appear to have lived in a sea not favorable to their full growth or development."

The section made by Professor Davis a few miles farther eastward has already been noted. I have examined the rocks at this locality and

* Characteristic Carboniferous fossils were found in the uppermost strata of number 1, establishing its age beyond any doubt.

found a close correspondence with the section made by myself on Belt creek. Fossils collected by Davis from these same shales, supposed by him when in the field to be Jurassic, were reported to be Spergen hill types by Professor Whitfield; this places them in the lower Carboniferous. The list given by Professor Whitfield is as follows:

Rhynchonella mutata, H.	*Terebratula turgida.*
Productus tenuicostatus, H.	*Allorisma*. sp.?
Athyris trinucleata, H.	*Lingula*, sp.?
Eumetria verneuiliana.	*Stictopora*, sp.?

These species and those enumerated above do not include a single characteristic Jurassic type. Notwithstanding the wide range of many of the species, and in general of the molluscan fauna so abundant in the Carboniferous, rendering such paleontologic evidence by itself of little value in determining exact horizons, it is noteworthy that fossils characteristic of the lower Carboniferous should be found in beds formed during the very close of the Carboniferous period. It should be noted in this connection that fossils from a very much lower horizon in the section made by Professor Davis are described by Whitfield as upper Carboniferous. The stratigraphic position and lithological character of the limestones and shales from which the fossils collected by myself were obtained correspond closely to those of the beds found in southern Montana to be characterized by an abundance of Jurassic fossils.* Such a decided change in the upper part of the Carboniferous from that observed elsewhere indicates a local modification of prevailing conditions and nearness of a shore line.

The Jurassic.—This shaly series is overlain by a bed that is characteristic of the Jurassic throughout central Montana. In its lower portion it is frequently a good crystalline limestone, passing gradually into a coarse sandstone, frequently a conglomerate closely resembling the Dakota but carrying large numbers of Jurassic shells in both the sandy and limestone portions of the bed (number 6 of the section).

The Belt creek section gives a total thickness of 538 feet of beds between the white limestone of the Carboniferous and the Jurassic.

The Kootanie.—Overlying the Jurassic conglomerate bed (number 6 of the section) there is a series of rather thinly bedded standstones of varying degrees of coarseness and induration. Near the mountains these rocks are ferruginous and bright red in color, but farther away from the uplift they are white and contain intercalated beds of shale and ferruginous sands. A 5-foot bed of dense yellow sandstone, quite impure and argillaceous, forms a recognizable division of this sandstone series. The

*Cf. W. H. Weed, Cinnabar and Bozeman Coal Fields: Bull. Geol. Soc. Am., vol. 2, 1891, pp. 352–360.

coal occurs above this sandy belt, 1,479 feet above the mountain limestone of the Carboniferous and 520 feet above the conglomerate carrying Jurassic fossils.

No plant remains whatever have been found in the shales resting upon the coal. Careful search was made at every opening of the seam for traces of plants, but with the same lack of success that attended the efforts of previous investigators. Slabs containing indeterminate shells of *Unio* were once sent to Professor Newberry as coming from the roof of the seam, but I found no fossils of any kind.

Overlying the coal seam there is a prominent ledge of massive and dense coarse sandstone capped by a series of rapidly alternating beds of lilac-tinted or pink sandstones and red and purple shales. Like the same beds at Great Falls, the sandstones form an excellent building stone. This series is capped by an impure yellow limestone full of gasteropod shells, which were forwarded to Dr. White for examination. His assistant, Mr. T. W. Stanton, reports that these fossils consist of three forms of fresh or brackish water types, viz, (1) *Neritina*, sp., resembling *Neritina* (*Neritella*) *nebrascensis*, M. and H., from supposed Jurassic beds at the head of Wind river, though the specimens (casts) are not well enough preserved for positive identification; (2) *Goniabasis* (?), sp., some of the more distinctly carinated forms very much resembling *Goniabasis tenuicarinatus*, a Laramie species, though it is probable that all the elongate gasteropods in this collection represent a single variable undescribed species belonging to that section of *Goniabasis* which includes *G. tenuicarinata* and *G. anltortuosa*; and (3) some fragments of a small bivalve that may belong to the genus *Corbula*.

The beds from which the plant remains determined by Professor Newberry were obtained are similar to those lying above the coal seam and between it and this limestone, and they form the northern extension of the same horizon.

The section above given represents the general characters of the Kootanie formation throughout the field; briefly described, it is a series of rapidly alternating sandstones and clay-shales, with few and thin beds of impure limestone. Individual beds are inconstant, the heavy ledges of firm sandstone passing laterally into arenaceous clays, and *vice versa*.

The Dakota.—No definite recognition of the Dakota has been made, and therefore only an arbitrary upper limit of the Kootanie rocks can be assigned to the section on Belt creek. The gasteropod-bearing limestone just alluded to is capped by a massive and rather coarse sandstone bed 25 feet thick, which forms the top of the table-land 200 feet above Belt creek. This is covered by a series of shale beds, black, purple and red, carrying thin beds of sandy limestones and passing upward into a

decidedly arenaceous shale that resembles the shales frequently found in the Dakota of this region; but the typical Dakota conglomerate of more southern localities is entirely wanting, nor is there any distinct sandstone zone of sufficient importance to replace it. The section of 780 feet to the top of Belt butte shows a series of black carbonaceous shales with sandy and flaggy shales and thin beds of sandstone. Number 21 of the section is a bed of massive, coarse sandrock, 50 feet thick, that forms the "belt" about the butte, and number 24 is a white and hard limestone that forms the upper belt or crown. The top rock is a gray sandstone underlain by black carbonaceous shales. Careful search was made for fossils, but nothing whatever could be found.

As noted farther on in this paper, the coal seam passes under the creek (at the mouth of Little Belt creek); and beyond this point to its confluence with the Missouri, Belt creek cuts higher strata, the bluffs of the Missouri at fort Benton belonging to the Fort Benton group.

Descriptive Geology.

As it was deemed quite important to establish the exact horizon of the coal seam relative to the shales from which the leaf remains were obtained, the beds were traced continuously by means of ledges exposed along the Missouri river and the walls of Sand coulée from Black Eagle falls to the coal mines at Sandcoulée and across the plateau from the latter place to the mines of Belt creek.

At Black Eagle falls, the first of the series of cascades below the city of Great Falls, the river bluff is about 150 feet high, exposing a good natural section, the rocks of which were even better exposed in the cuttings made for the dam and for the foundations of the smelter on the western side of the river. Arranged in tabular form, this section is as follows:

	Thickness in feet.
Hill top, on which the smelter chimney is erected.	
21. Sandy shale, greenish	20
20. Sandy shale, red and purple	15
19. Sandrock ledge, fissile, not prominent	5
18. Clay and red shale	15
17. Clay and sands, green and gray	3
16. Clay, red and leafy shale	5
15. Ironstone forming caps to sandstone pillars	1
14. Sandstone, crumbling, weathering into pillars and buttes; this is but a lens of sandrock in a clay series	10–30
13. Clays	10
12. Sandstone ledge; forms top of river bluff	25–30
11. Clay-shales, red and gray on weathered slopes, blue-gray in fresh exposures	50

	Thickness in feet.
10. Sandstone ledge, gray and hard	2
9. Shales, gray or red	15–20
8. Gray sandstone	5
7. Limestone, decomposed, brown, splintery	$2\frac{1}{2}$
6. Shale, easily crumbled, green-gray	5
5. Sandstone, passing into shales at base	7
4. Shale and shaly sandstone, rotten, red-brown	9
3. Sandstone, massive ledge, forming fall of river	7
2. Flagstone, purple and lilac sandrock	12
1. Sandstone, massive, square block jointing	5

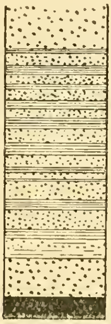
At the top of the section there is a sandy series (numbers 16–21) whose erosion has formed most picturesque and brilliantly colored miniature badlands. The beds change rapidly horizontally, passing into the lilac sandstone (freestones) and clay-shales, the sandstone being an excellent building material and easily quarried and much used. The clay-shales interbedded with them hold the beautiful ferns identified by Professor Newberry. These beds rest on a massive layer of buff sandrock containing thin seams of lignite which, traced southward, is found to correspond to the sandrock above the coal seam. This ledge illustrates the difficulty of following a particular ledge of sandstone any considerable distance, for it passes into clays and sands a few miles to the northward, and is not a decidedly recognizable horizon at the south. Beneath this sandrock, forming the top of the bluff, there is an alternating series of clay-shales and sands, which are blue and gray where freshly cut for the walls of the new smelter, but generally weather reddish or brown; beneath these shales, a ledge of soft granular sandstone caps a series of soft clay-shales, resting upon the lilac-colored or pinkish sandstones forming the falls—rocks that pass laterally into red clays half a mile down stream.

Traced southward, the upper members of the section are seen to form the slopes about the city of Great Falls, the city dam being built on a sandstone ledge corresponding to number 12 of the foregoing section. South of the city the eastern bank of the Missouri shows exposures of red clays with freestones and shales that are quarried at a number of points between the city and Sandcoulée. At the mouth of the valley known as Sand coulée, where the creek empties into the Missouri, a ledge of white quartzose sandstone outcrops on the slope some 25 feet above the river; it corresponds in horizon to that on which the city is built, and forms a readily traceable ledge extending up the coulée to the coal mines. It is capped by rather thinly bedded, square-jointed, lilac or pinkish sandstones and alternating slate beds, which form excellent building stone. Following these beds up the coulée the coal seam does not appear until reaching a branch of Sand coulée known as Straight coulée, on

which the Sandcoulée mines open, where the coal appears beneath the massive sandstone ledge traced up the valley. At the mines it is about 20 feet thick and is a hard white quartz rock. The coulée slopes are generally drift-covered, but a natural section is exposed where the wagon road ascends the plateau, showing the following beds:

	Feet
Sandstone	30
Shaly beds	25
Sandstone, square-jointed, buff; really a pebbly grit	3
Shaly beds, purple and red, crumbling	(?)
Shaly beds, pebbly, gray and green, crumbling	(?)
Sandstone ledge, same as that over coal; no coal seen.	

Where the wagon road descends into Straight coulée, near the coal banks, the following strata are exposed:



	Feet
Sandstone, forming summit of plateau.	
Sandstone and sandy shales, red and gray, alternating beds.	50
Shales and clays, red and buff	50 to 75
Sandstone, forming bed above coal seam	20
Coal seam	12

FIGURE 4.—*Section on Sand Coulée.*

The plateau summits are quite gently undulating surfaces, well grassed but bare of trees or shrubs, with a covering of glacial drift not of sufficient thickness to produce a marked drift topography but filling preglacial hollows. Bowlders are not common but include a variety of rocks—granite, limestone, etc—found in the Belt mountains.

SANDCOULÉE BASIN.

Structure.—That portion of the Great Falls coal field adjacent to the Sandcoulée mines can best be alluded to as the Sandcoulée basin. In prospecting the field it has been found that the seam thins out toward both the north and the south from the mines. Toward the west the seam splits into two beds, separated by 25 feet of shale, but probably is continuous, if not workable, to the bluffs of Smith river, though the prospecting indicates a shallow basin.

The following section represents the strata exposed on McGriffin coulée, a branch of Sand coulée, near the coal mines:

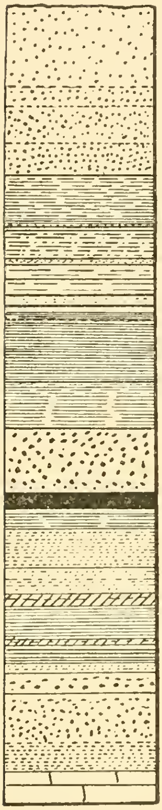


FIGURE 5.—*Section at Sandcoulée.*

The only working within this basin and the chief mine of the entire field is that of the Sandcoulée Coal company. In the prospecting of the basin by this company several drill-holes were driven, which furnish complete sections of the strata above the coal seam. By the kindness of President Cocker* I have been placed in possession of the records of these drill-holes, sections of which are presented in the accompanying table. Though sections of precisely identical strata, they differ somewhat in detail and show the local changes of particular strata. The three borings, designated respectively as numbers 1, 2 and 3, lie in a north-and-south line at intervals of half a mile.

* I am under obligation to him and to Superintendent Burrill for many courtesies and for valuable information.

Diamond Drill Records at Sandcoulée.

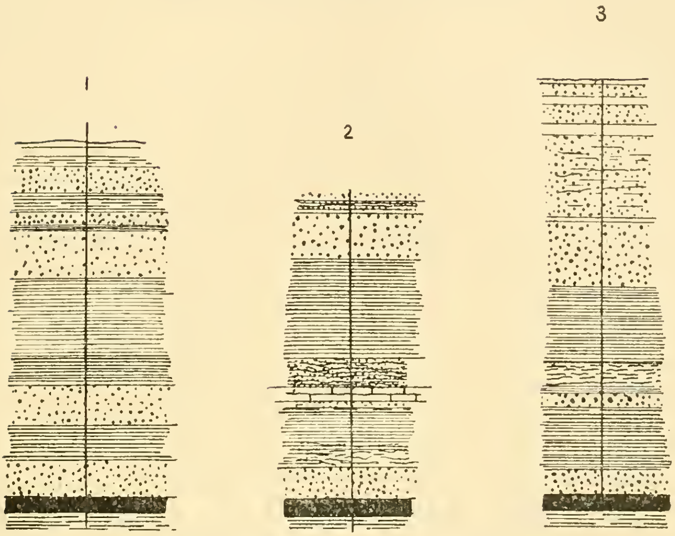


FIGURE 6.—*Sections revealed by Drilling at Sandcoulée.*

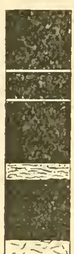
NUMBER 1.	NUMBER 2.	NUMBER 3.
Soil ... 1′ 6″ Ironrock ... 6′ 6″ Red shale ... 5′ Sandrock ... 14′	Soil ... 1′ 6″	Soil ... 2′ Sandstone ... 6′ Red shale ... 6′ 6″ Yellow sandstone ... 10′ Pink shale ... 6′ White sandrock ... 20′ Hard yellow sandrock ... 5′
Clay and shale ... 10′ Yellow sandstone ... 7′	Light shale ... 9′ Sandrock ... 4′ 6″	Light yellow sandrock ... 16′
Black slate and mud ... 41′	Black slate ... 21′ Gray and black slate and clays ... 14′ Blue clays ... 18′ } 53′	Clay ... 3′ Sandstone ... 4′ Black slate and mud .. 20′ Limestone ... 3′ Cream-colored shale ... 12′ } 42′
Blue clay ... 14′ Sandstone ... 22′ Clay-shale and mud. 10′ Light shale ... 10′ } 20′ (Clay-shale and mud, Light shale)	Sandy yellow clay ... 15′ Limestone ... 7′ Sandy red shale ... 3′ Gray shale ("soapstone"). 32′	Yellow clay ... Limestone ... } 18′ (Yellow clay, Limestone) Sandstone and conglomerate ... 6′ Slate, running into above ... 33′ 6″
Sandstone ... 19′	Sandstone ... 15′	Sandstone ... 12′ 6″
Black slate and coal 2′ Clay and slate ... 1′ 6″ Dark slate and coal. 1′ 4″ Slate ... 1′ Slate and coal ... 2′ 7″ } 8′ 5″	Coal ... 0′ 10″	Coal ... 6′ 8″ Slate ... 1′ 5″ Coal ... 0′ 11″ } 9′
Black slate ... 3′ Clay ... 4′ 6″		Slate ... 1′ 5″ Clay ... 2′ 1″

Sandcoulée Coal Mines.—The Sandcoulée coal mines are twelve miles from Great Falls by rail and six miles east of the Missouri river. Like the rest of the coal field, the country about the mines is a rolling plateau, locally cut by the numerous branch coulées tributary to Sand coulée. The mines are opened in the banks of one of these tributaries called Straight coulée. The coal lies beneath a sandstone ledge that generally outcrops upon the coulée banks, the slopes above it being generally grass-covered and showing no exposures. There is a slight dip of the beds to the northward, affording easy drainage and haulage.

The property now being worked shows an excellent fuel coal that can be economically mined and is near enough to the point of consumption to avoid excessive freight charges. Unfortunately for the early reputation of the product, the working was begun in an area of "dead" coal. Experience has shown that where tributary coulées have cut down the overlying strata the coal has lost its virtue and is high in ash and low in volatile carbon, and its physical constitution is such that it is of very inferior quality. It was in such an area that the early working was done; and this, combined with the fact that in mining the entire seam, as was formerly done, a large amount of slate got into the coal from the parting above the lower bench (a parting that is now used as a floor in the rooms), led to unmerited prejudice against the coal from this mine.

Throughout the workings at Sandcoulée the seam shows a considerable variation in thickness, the upper benches now worked being from $3\frac{1}{2}$ feet to 7 feet thick. The quality also varies with the proximity to the surface of the overlying ground in the manner already stated, and appears also to depend somewhat upon the thickness of the slate roof between the coal and the overlying sandrock. For the first 1,000 feet from the main entry the coal is "dead," the gases having escaped through seams in the sandstone roof; and the coal east of this entry is similarly affected.

The following average section of the seam shows its character:



Top coal	23–28 inches.
Parting	$\frac{3}{4}$ "
Coal	10 "
Parting	1 "
Coal	24 "
Parting	6– 8 "
Coal	24 "

FIGURE 7.—*Section of Sandcoulée Coal Seam.*

On account of the thick parting above the bottom bench the coal is not mined except in driving entries. The top coal consists of an upper layer of 10 to 15 inches of dull and quite hard coal called "anthracite," but carrying quarter-inch streakings of bright coal. Below it the coal is mixed, dull and bright, down to the uppermost parting. The second bench is a bright bituminous coal and, like the bench below, is an excellent fuel, but carries balls of pyrite that cause much annoyance in mining and prevent the use of the coal for many purposes.

Samples representing the average quality of the different benches of coal were collected and have been analyzed for me by Dr. Stokes, of the chemical laboratory of the United States Geological Survey. The analysis of the top coal shows—

H_2O	3.66
Volatile hydrocarbon	30.88
Fixed carbon	55.50
Ash	9.96
	100.00

A sample of the coal from the middle of the seam shows a very large amount of ash, and is evidently the cause of so much complaint that the coal output is dirty. The analysis gave—

H_2O	2.68
Volatile hydrocarbon	26.36
Fixed carbon	44.02
Ash	26.94
	100.00

A third sample, from the lower bench, shows a cleaner coal, low in ash and higher in volatile combustible matter, possessing coking qualities that fit it for many uses for which the coals of the upper bench are not available. This bottom coal should be economically mined and separated with present methods of working. Under the present management the large amount of ash experienced in using this fuel must be charged to the coal itself and not to dirt from the partings.

An examination of the seam as exposed throughout the workings shows that the thin partings in the upper portion are quite variable in thickness and position and are occasionally wholly absent. Their maximum thickness is about 2 inches. The lower parting is always present and can be counted upon as to both position and thickness. As a rule the roof is good, there being from 6 to 18 inches of slate over the coal. When this slate is but 6 inches thick it is difficult to keep the roof up, but when it reaches 18 inches the roof is perfectly safe. Throughout the mine the roof rolls in gentle undulations.

The floor of the newer workings is the thick parting of slate over the bottom bench of coal. In driving the entries this lower coal is extracted, and there is some 3 feet of slate between the coal and the underlying sandrock. The floor rolls up and down a good deal but runs into regular strata.

The mine at present is worked by the pillar-and-room system. Two main entries are run, with side entries driven at right angles to them. The main entries are 24 feet wide, timbered where the roof slate is thin, but usually having a line of pillars in the center only. The right-angle entries are driven 12 feet wide at the roof and no timbering is necessary. The usual 30 feet of coal is left between the air entry and the main entries. The rooms are 24 feet wide, with a 12-foot pillar, and cross-cuts every 100 feet; but where the coal-cutting machines are used the rooms are 50 feet wide with a 15-foot pillar, and 20 feet between belts.

The miners are, as usual, paid by the amount of lump coal delivered, weighed as it is dumped over screens into box cars, an automatic scatterer being used for loading. The nut coal averages 15 per cent of the output, and there is 10 per cent of slack. The nut coal meets with a ready sale, and the slack is hauled away by the Great Northern railway and used as ballast. The cost of ordinary outdoor labor is $2.50 per day. The miners are paid at the rate of $1.00 per ton.

Belt Creek Basin and Mines.

As the plateau summit between Sand coulée and Belt creek is drift-covered, no continuous ledge can be traced: but the low inclination of the beds and the exposures seen on Box Elder creek and its tributaries are sufficient to establish the identity of the coal strata of Belt creek with those of Sand coulée. The prominent features of the topography are the flat table-lands which extend eastward to the slopes of the Highwood mountains and southward to the uplands of the Belt range. Natural sections of the strata are found in small drainage cuttings trenching the plateau walls. These are sufficiently illustrated in the general section already given, which was made here.

The strata of the Belt creek basin possess a gentle northerly dip with an extremely gentle local anticlinal fold in the center of the basin. The rocks of the coal measures are the same as those found along Sand coulée. The coal lies beneath a cap-rock of hard quartzose sandstone 60 to 75 feet thick in the southern part of the basin, though but 25 feet thick at the Armington mines. It is a coarse gray, very massive sandstone, having a prominent outcrop tinted pink by the wash from the shales above. The slopes above this ledge are usually grassy and show

no exposures up to the summit of the table-land, 200 feet above the valley bottom at Armington; but sections of the rocks forming the table are seen in small lateral drainage cuttings.

The rocks beneath the coal are seldom exposed, as the seam is generally but 50 feet or so above the creek. Where the beds are cut by the railway line in the northern part of the basin the following rocks were found exposed:

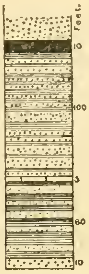


FIGURE 8.—*Section near Bell Creek.*

At Armington similar rocks are exposed near the railway bridge.

The largest opening is the Castner mine, which was formerly worked to supply the Fort Benton demand. The main entry is some 600 feet long, of which 115 feet only is timbered. In the rooms, pillars and caps are used to support the roof. The seam shows a total thickness of 12 feet, the uppermost 3 feet being too slaty and dirty to work and showing but 12 inches of coal. The bottom bench shows 20 inches of clean coal that is used for blacksmithing purposes.

On the eastern side of Belt creek is the Millard claim. The section of this seam is essentially the same as that of the Castner mine, as will be seen by the diagram (figure 10). In the room now being worked the seam shows the following section:

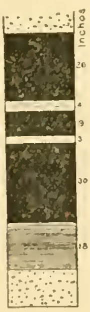


FIGURE 9.—*Section in Belt Field.*

The coking coal is separated in mining and sold separately for blacksmiths' use. The second parting is not separated.

Examinations of the coal bed, made at the various openings of the Belt basin and other parts of the Great Falls field, show the following sections:

Sections of Coal Seams of the Great Falls Field, Montana.

	Castner mine.	Millard mine.		Watson mine.	Armington mine.	Sand Coulée.
		Entry.	Room.			
Roof, sandrock	....	....	....	....	....	Sandrock Slate 9″ Coal 28″
Slate	5″	10″	0	0	16″	$\frac{3}{4}$″
Coal	20″	20″	26″	24″	21″	10″
Slate parting	6″–10″	2″	4″	6″	6″–10″	1″
Coal	12″–15″	10″–12″	9″	12″–16″	10″	24″
Slate parting	4″	6″– 8″	4″	6″– 8″	3″– 4″	6″– 8″
Coal	20″	24″	18″	30″–36″	14″	24″
Floor	....	....	....	....	....	....

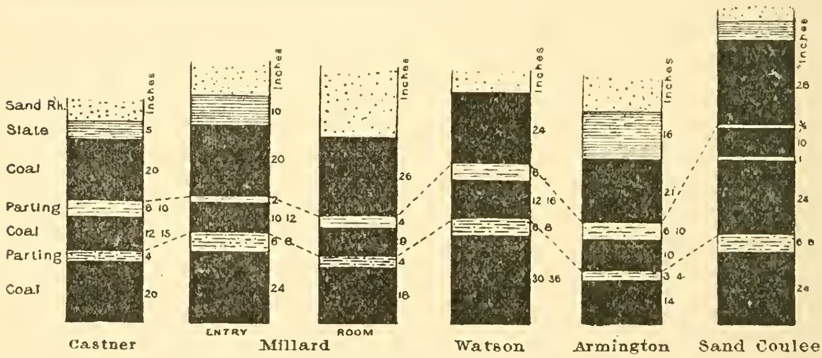


FIGURE 10.—*Sections of Coal Seams of the Great Falls Field.*

The Belt creek mines are now worked only for household fuels, but their consolidation has already been effected and their further development is likely to be accomplished in the near future, now that railroad facilities are afforded by the Neihart road.

The coal seam thins rapidly north and south of Belt. On the north it is but 2 feet thick some two miles below Belt, and thins out near the mouth of Little Belt creek, where the coal dips beneath the creek bed. Toward the south the seam thins out and deteriorates in quality toward Otter creek, and although it has been found on Otter creek and opened near Mann post-office (Otter), the seam is but $3\frac{1}{2}$ feet thick, the bottom bench only being workable.

An average sample of this coal taken by the writer and analyzed by Dr. H. N. Stokes, of the United States Geological Survey laboratory, shows the following composition:

H_2O	3.05
Volatile hydrocarbon	41.01
Fixed carbon	52.31
Ash	3.63
	100.00

The roof here shows 10 inches of slate between the coal and the sandrock, and the roof rolls slightly, pinching the seam. The two partings are always present, the upper one varying, the lower very constant. The top coal is long grained down to the lowest 4 inches, which breaks into dicey bits.

The Castner and Millard mines are in the center of the Belt basin. About a mile north of the latter the Watson mine shows the seam to be 11 feet thick, the upper 3 feet being too dirty to work. The section shows the seam to be quite dirty and the coal, particularly the lower bench, sulphurous. The roof is uniform and flat. The structure is as follows:

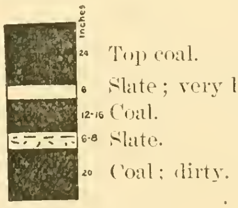


FIGURE 11.—*Section at Watson Mine.*

North of this mine the seam is not worth working, so far as shown by the prospects yet driven.

South of Belt there are several openings at Armington, which show the seam to be constant in character and to hold an excellent free coal. In the old entry of the Armington mine, abandoned on account of a roll of the seam, the following section of the coal was obtained 500 feet under cover:

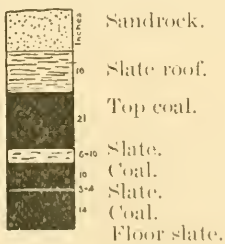


FIGURE 12.—*Section at Armington.*

Similar sections at the other openings show that the seam, though less free from parting dirt than at Sandcoulée, is yet a valuable property. The coal from many of the openings shows peacock tints and, like that of Sandcoulée, holds pyrite balls. The openings at this part of the field show generally a firm sandrock roof over the coal.

Other Parts of the Great Falls Coal Field.

The Otter Creek coal has already been mentioned. The seam is too thin to pay working, and whether it thickens to the south in a continuation of the Belt Creek basin, as present indications appear to point, can be determined only by drill prospecting, as natural exposures are wanting.

Nothing is known of the eastern extension of the Great Falls field about Dry Arrow, Sage and Willow creeks and the Judith basin, save the notes made by Eldridge for the Northern Transcontinental survey, though the country has been prospected for several parties by local experts; but the seam shows a workable thickness that will be of value when the Judith basin is traversed by a railroad.

The western extension of the Great Falls field shows a promising thickness of coal at several points. The coal seam outcrops in the bluffs of Smith river and at Hound creek, but the openings are of small extent and are not worked at present. The coal seam is in a steep bluff some 300 feet above the river and shows a thickness of 5 feet 9 inches. Its character is much like that of the Sandcoulée coal—a roof of hard slate caps a dull coal, which lower down is streaked with bright coal. A thick parting of sandy shale separates this upper bench from a good coking coal below.

A mile and a half up Hound creek the seam is said to be but four feet thick and to thin rapidly toward the south. To the northward the seam thins out to four feet in the bluffs of Mings coulée, where it dips toward the south, showing a shallow basin.

The seam is also reported to outcrop at the base of the mountains at the head of Bird creek, near Chestnut, and but a few miles beyond.

As further exploration of the field is made in the search for special grades of fuel better fitted for metallurgical purposes, there will be more information available concerning the extent of the field and the geology of the Kootanie formation.

Age of the Great Falls Coal.

To Professor J. S. Newberry belongs the honor of first establishing the age of the Great Falls formation. The fossil plant remains upon which this identification rests have been obtained from two localities: (1) a

railroad cutting 5 miles above the mouth of Sun river; and (2) a ravine exposing the plant-bearing shales on the northern side of the Missouri opposite the city of Great Falls. At the first locality ferruginous concretions were obtained containing well-preserved leaf impressions. The following species have been reported from this locality by Professor Newberry:

Zamites montana, Dawson.	*Podozamites latepennis*, Heer.
Sequoia smittiana, Heer.	*S. fastegata* (?), Heer.

Professor Newberry says, "These plants prove beyond question that the Great Falls coal basin is of the same age with those that have been described north of the boundary line by Dr. George M. Dawson in what he has designated as the Kootanie series." "The strata here dip to the north, the coal passing under the barren sandstones and shales which form the falls of the Missouri, and all the bedded rocks are concealed by drift as far as observation has extended northward of the river." Detailed observations by the writer having confirmed this statement, the plant remains found in the rocks north of the Missouri and opposite Great Falls afford evidence of the Kootanie age of the coal measures, as well as proof of the age of the barren strata.

A small collection of plant remains obtained for the writer by Mr. H. S. Williams, of Great Falls, the discoverer of the first fossils found in the formation, was submitted to Mr. F. H. Knowlton and by him sent to Professor W. M. Fontaine, together with a collection made by himself. Professor Fontaine has written an interesting report upon these fossils, which will appear in the proceedings of the United States National Museum. The collections consist mainly of well preserved impressions of ferns, many of them new species, besides a number previously identified from this locality by Professor Newberry. There are in addition a few conifers and an equisetum.

The most interesting feature of Professor Newberry's latest paper was the correlation of the Great Falls, Kootanie and Potomac formations, the fossil floras of all three having many species in common. This is sustained by the later collections mentioned above, though most of the species identified by Professor Fontaine have not been identified in the Great Falls formation before.

2. NOTES ON THE ROCKY FORK COAL FIELD OF MONTANA.

Location and general Features.

The Rocky Fork coal field lies at the foot of the Beartooth mountains and south of Yellowstone river, Montana. The quality of coal, the thickness and great number of the seams, with the unproved extent of the field, make it of great importance notwithstanding the distance to the larger centers of consumption. A branch line leaves the Northern Pacific railway at Laurel, 13 miles west of Billings, and runs up Clarkes fork of the Yellowstone and its tributary, Rocky fork, to the mines and the mining town of Red Lodge.

The topography of the field is of a type common along the eastern base of the mountains. Very gently sloping plains abutting sharply against the steep rocky slopes of the mountains stretch out for many miles northward. These plains are trenched by longitudinal drainages, the larger streams from the mountains flowing in rather broad gravel-filled valleys, the smaller streams heading in the plateau cutting down the benchland slowly and exposing the tilted and eroded rocks which form the mesa. Toward the south the mountains rise abruptly in rocky, buttressed slopes to the crest of the Beartooth range, an unexplored glacier-crowned mountain mass having the highest peaks in Montana. Toward the north the table-land fades into the benchland and rolling hills of the Crow reservation, a well watered country with broad alluvial bottom lands and well grassed uplands, greedily coveted by the settlers of the surrounding country. The mountain slopes and valleys are wooded with a heavy growth of pine timber, but the table-lands of the coal field are bare of trees and shrubs, save along the water-courses, though well grassed and bright with the colors of innumerable flowers.

The general features of the geology of the region are simple; a section shows a series of sandstones resting on the marine cretaceous in the valley of the Yellowstone, dipping gently from 3° to 5° toward the mountains but disturbed by gentle warping of the beds. These sandstones, which near the mountains dip more steeply (averaging 15°) and carry the coal seams, are faulted against the Paleozoic limestones which form the mountain flanks; the latter weather in great combs and ledges, dipping away from the mountains at high angles.

The benchlands which form so conspicuous a feature of the coal field are covered by a thick mantling of more or less rounded drift, sometimes to a depth of 160 feet. This gravel effectually conceals the truncated

edges of the underlying coal measure sandstones and makes it extremely difficult to outline the extent of the field.

A very brief but comprehensive account of the coal seams of this field was published by J. E. Wolff,* who visited the locality before the mines were opened.

Extent of the Field.

Very little is thus far known of the extent of the Rocky Fork field. Prospecting has been confined to the vicinity of the Red Lodge mines, being chiefly done in the broken country to the eastward, where the deep trenches of streams have exposed the coal seams. The coal has been traced and found to be workable at least as far eastward as the Clarkes fork bottom. Westward no prospecting whatever has been done, and therefore the presence of the coal is not proved; but the same geological structure and the same rock series has been found by the writer to extend for many miles westward, and there is no reason to doubt the continuity of the coal measures in this direction, although prospecting with drills will be necessary to prove the value of the land.

The southern boundary must perforce be the fault line that runs along the base of the mountains; the northern boundary of the field is at a variable distance of 3 to 4 miles from this fault line, according to the dip of the beds.

The Coal Measures.

Structure.—The coal seams occur interbedded with coarse gray and buff sandstones and thin clayey shales, such as characterize the coal rocks of the Bozeman field. Fossil leaf remains are found in these sandstones and rather well preserved shells of *Unio* in the slates over the coal. The total number of coal seams is not known, but nineteen have been examined, of which six have been mined at Red Lodge. Of the nineteen seams examined, eleven show over six feet of coal.

About the town of Red Lodge the coal measures outcrop as heavy sandstone ledges and shale belts on the eastern bluffs of the valley. The prevailing dip is 15° southward or toward the mountains. The eroded edges of the beds are covered by gravels known to be from 20 to 160 feet thick in the vicinity of the town and forming the surface of the level benchlands in which the valley is cut. On the south the beds flatten out toward the fault that brings the coal measures against the white limestones of the Paleozoic. The coal rocks are cut by a dike of igneous rock a mile above the town, a prominent ledge that was traced for several miles to the eastward, trending southeasterly. The creek, issuing

* Tenth Census, vol. xv, Washington, 1886, p. 755.

from the mountains through a sharp cut in the upturned limestones above the town, flows through the bowlder-filled channel, whose well grassed valley slopes show no exposures until the town is reached.

To the westward, crossing the broad benchland cut by shallow grassy drains, the low ridge about 3 miles from the town forms the terminal edge of a rising alluvial or wash slope or cone, the drift being wholly local and mainly limestone from the neighboring mountain slopes. About the head of a considerable drainageway that has cut down into the soft sandstones overlying the coal measures, the strata are seen to dip gently southward toward the fault. The rocks are mainly sandstones, rather soft, and weathering into loose sands that form smooth grassy slopes, with intercalated clayey shales and more rarely thin beds of limestone. Westward the country is more broken and the slopes show similar southward-dipping beds, while toward the north the broad bench lands continue for many miles. East of Red Lodge the branches of Bear creek, a lateral tributary of Clarkes fork, have cut back the bench, forming a deeply gullied and hilly country, locally called "badlands." Here the coal measures lie much flatter than at Red Lodge, and the coal seams have been prospected at a great number of points. It is a promising part of the field, but is dependent upon a railroad for its development.

Red Lodge Mines.—The only mines now operated in the Rocky Fork field are those of the Rocky Fork Coal company at Red Lodge; to Dr. Fox, the manager, and the other officers of this company, I am indebted for many courtesies and much information. Six seams have been worked, three of which are not being mined at present, owing to their inferiority to the others. The seams have an average thickness as follows: Number i (most southerly seam mined), 6 to 7 feet; number ii, 7 to 10 feet; number iii, 6 to 7 feet; number iv, 12 to 13 feet; number v, 12 feet; number vi, 5 feet.

Number vi is geologically highest of those worked, but 120 feet above it there is a 3-foot seam of coal, and 600 feet farther up the creek an 18-inch seam of coal. Below number vi there are nine seams outcropping in the creek bluff, of which five show over 6 feet of coal, the best being perhaps number viii. The farthest seam is about a mile below the mines and is opened by a drift 100 feet long. The coal is 6 to 7 feet thick, strikes east-and-west magnetic, and dips 10° southward. The rocks between this seam and the mines are sandstones and gray shelly shales, barren of fossils and strictly conformable. No outcrops occur below this seam.

Number i is no longer mined. It is the original "Yankee Jim" seam, and is a good coal; but the other seams are worked cleaner. The tunnel was not safe to enter, owing to gas, so that no section was obtained.

Seam number ii is opened by an entry main 2,000 feet in length. Cross-sections of this seam, made at the end of this entry, and of seam number

iii, show the benches and partings represented in the first two columns of the accompanying table and figure 13. Seam number ii dips southward 15°. The upper bench of coal, 24 inches thick, is left up in the rooms to form the roof. The sandstone lying above the seam occasionally cuts out the slate over the coal. The thickness of coal is 7 feet 8 inches; coal worked, 5 feet 2 inches. The roof of seam number ii is a soapstone. This seam, though showing several thick benches, is not worked on account of the partings. If worked in the future it will be by the long-wall method.

Coal Seams of Red Lodge Mines.

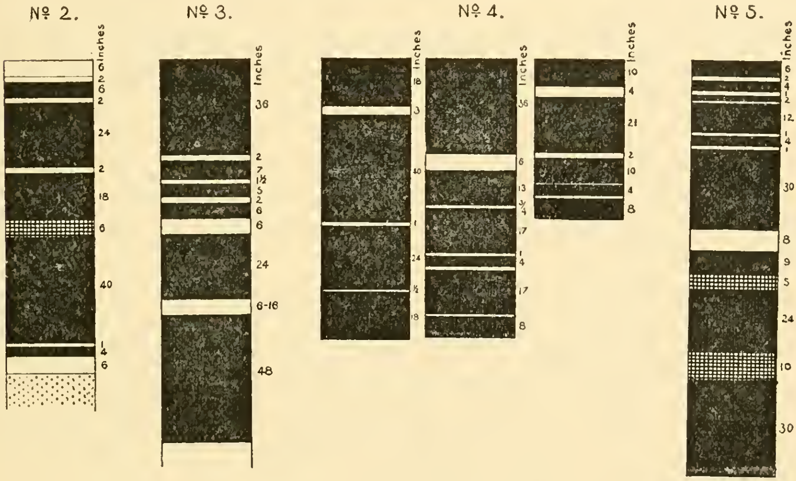


FIGURE 13.—*Coal Seams of Red Lodge Mines.*

Number ii Section.

Sandstone roof.	
Slate	6″
Slate	2″
Coal	6″
Slate	2″
Coal	24″
Parting	2″
Coal	18″
Dirt	6″
Coal, clean, shackly, fractured	40″
Parting	1″
Coal	4″
Fire-clay	6″
Sandstone.	

Number iii Section.

Coal	36″
Slate	2″
Coal	7″
Slate	1½″
Coal	5″
Slate	2″
Coal	6″
Clay and dirty coal	6″
Coal, clean	24″
Fire-clay	6″–18″
Coal	48″
Slate.	

Number iv Section.

Coal	18″
Clay	3″
Coal	40″
Parting	1″
Coal	24″
Parting	½″
Coal	18″

Coal	36″
Parting	6″
Coal	13″
Parting	¾″
Coal	17″
Parting	1″
Coal	4″
Parting	1½″
Coal	17″
Parting	½″
Coal	8″

Coal	10″
Clay	4″
Coal	21″
Clay	2″
Coal	10″
Parting	¼″
Coal	4″
Parting	¼″
Coal	8″

Number v Section.

Coal	6″
Parting	1½″
Coal	4″
Parting	1″
Coal	2″
Parting	½″
Coal	12″
Parting	1″
Coal	4″
Parting	1″
Coal	30″
Fire-clay	8″
Coal	9″
Coal dirt	5″
Coal	24″
Dirty coal	10″
Coal with lenses of parting.	30″

The fourth and fifth seams show the structure indicated in the diagram. The sections of seam number iv do not, of course, give the entire width of the seam, but only the portion worked. The roof is a firm sandstone, so that only the main entry, 18 feet wide, is timbered, and the slope the same. The seam is opened by a half mile of entry and a slope of 600 feet. These workings show the seam to have a dip of 18° at outcrop and 16° at the bottom of the slope, the roof being very constant. The floor is a soft gray shale having a slight roll. The lower partings of the seam are very constant, but the uppermost parting is quite variable in thickness. The seam has a nearly uniform thickness of 12 feet, of which 20 inches is left to form the roof over the rooms. The roof of this seam rolls considerably.

A 5-foot seam of coal lies between seams number iv and v, with 35 feet of rock between it and number iv; but the seam has too many partings to be workable.

Number v is but little worked, the mine being abandoned on account of the partings and the prevention of economical working by the bottom coal. The roof rolls but very little, not so much as number iv. The coal above the 30-inch bench is all one bench, or has but thin partings, of no consequence farther in.

Seam number vi is 5 to 6 feet thick and shows a clean bench of coal having only one parting of an inch in thickness about midway. The coal is bright and breaks into prismatic masses with hackly fracture. The roof rolls in strong waves and the floor also rolls. No timbering is done in the entries of seams numbers v and vi, but though the roof of number vi is a hard sandstone it is crushing in the rooms and is held up by timber cribs.

While the seams numbers i, iii and v are not mined at present, owing to the greater profit of mining the other seams, they are valuable for future supply.

The Rocky Fork Coal company holds 3,440 acres of property, being a strip about two miles wide (the entire width of the outcropping seams of the field) and some three miles long, comprising the high benchland and broken country about the head of Bear creek, east of Rocky Fork creek. To the eastward the seams flatten out to a dip of 5°, with low arching of the beds.

Bear Creek Mines.—In this eastward extension of the field the area available for mining has a much greater width, as the beds flatten out gradually toward Clarkes fork. In general the trend of the field is toward the southeast. Numerous locations have been made and short prospect entries driven on the seams that outcrop in the sides of the gulches. The most extensive working has been made by agents of Butte capitalists,

who opened a 7-foot seam of coal, but abandoned it after a year's working. Coal taken out of the old prospect entry near by, that has been exposed for three years, is hard and firm.

Taggart's claim, 4,500 feet in altitude by aneroid, shows a dip of 1° to 2° toward the south. A short entry shows the following section, which was taken at the outcrop and does not, therefore, fairly represent the seam:

Solid sandrock	
Decomposed brown clay	36″
Coal	24″
Lignite bone	42″
Coal, forming entry roof	12″
Bony, dirty coal	12″
Clean coal	4″
Slaty dirt parting	2½″
Coal, clean	23″
Carbonacious slate parting	5″
Coal	24″

This part of the field can be mined cheaply, owing to the flatness of the seams; but the narrow gulches give no dumping ground. The lack of transportation is the only great obstacle to the rapid development of the mine.

Near Clarkes fork the ridge shows a heavy outcrop of sandstone composed of granitic grains and forming ridges 150 to 175 feet high, the beds dipping southward 4°, and coal seams lying beneath the sandstones. East of Clarkes fork the soft clays of the Tertiary (?) appear, the river cutting through a low synclinal arch.

The continuity of the coal field toward the southeast is interrupted by the river valley and the eroded basin of Grove creek, now a broad wash-plain. At the head of this gravel plain the Cretaceous sandstones and clays, carrying lignites, dip 5° toward the mountains, the summit being about 5,320 feet in altitude, and the ledges abutting against a Carboniferous conglomerate dipping northward 75° and underlain by massive limestone cut into picturesque, castellated forms by the mountain torrents. The fault line extends southeastward, so far as can be seen, at least a couple of miles beyond here. From this point to the most westerly spot visited, some eight miles in all, the structure is the same. East of Clarkes fork, Pryer mountain shows beds dipping southward.

Age of the Rocky Fork Coal.

Below seam number i there is some 60 feet of sandstone weathered down to a slope, with a bold outcrop of massive sandstone some 30 to 40 feet in thickness below it. This rock is coarse, formed of granite débris,

and is cross-bedded and pitted. It shows poorly preserved leaf remains. Fossil leaf remains occur in a better state of preservation in the sandstones between numbers iv and v, where they have been quarried for building purposes. A collection made by the writer has been studied by Mr. F. H. Knowlton, who reports the species to present a decidedly Fort Union facies.

The remains of *Unio* obtained from the roof of seam number iv have been examined by Dr. C. A. White, who reports them to belong to two species, *Unio senectus*, White, and *Unio danæ*, M. & H. These species are of too widespread occurrence in the fresh-water Cretaceous rocks to fix any definite horizon.

In the lack of definite structural evidence of the age of the coal measures, we must therefore rely upon the plant remains. These are of Fort Union types and belong to a flora quite distinct, so far as studied, from that of the true Laramie, or that of the Livingston beds of the Bozeman coal field farther westward.

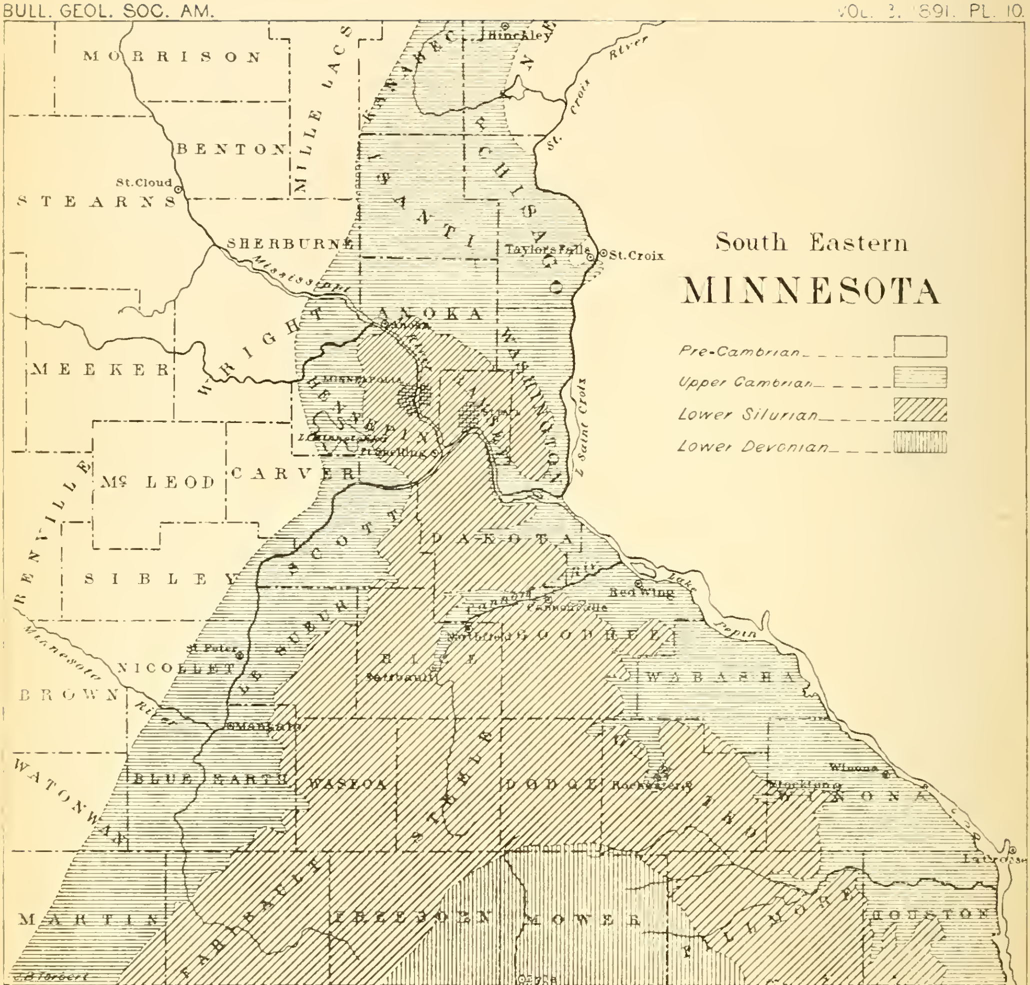
BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 331-368, PLS. 10-12

PALEOZOIC FORMATIONS OF SOUTHEASTERN MINNESOTA

BY

C. W. HALL AND F. W. SARDESON

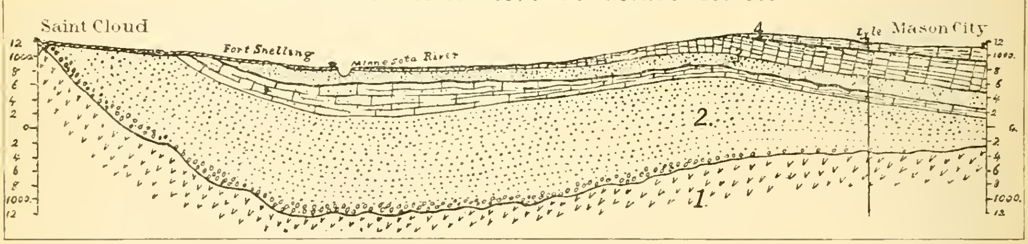
ROCHESTER
PUBLISHED BY THE SOCIETY
JUNE, 1892



PROFILE

From Saint Cloud, Minnesota to Mason City, Iowa.

Horizontal distance 150 miles; Unit of elevation 200 feet



Map and Profile of South Eastern Minnesota.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 331-368, PLS. 10-12 JUNE 23, 1892

PALEOZOIC FORMATIONS OF SOUTHEASTERN MINNESOTA.

BY C. W. HALL AND F. W. SARDESON.

(Read before the Society December 29, 1891.)

CONTENTS.

Introduction.

The rocks described in the following pages occupy the entire area of southeastern Minnesota, some 13,200 square miles in extent. They stretch eastward from a straight line between Mankato and Hinckley to the state of Wisconsin, and from Chengwatona southward to Iowa.

The periods of geologic time represented by these formations are three, viz. Cambrian, Silurian and Devonian. That portion of the Cambrian exhibited is the upper, of the Silurian the lower, and of the Devonian so thin a layer is present and so few fossils occur in it that we cannot assign the rocks to any division of that group, but suppose them to belong near the middle.

These Paleozoic rocks are underlain by the Archean and Algonkian, and lie beneath patches of Cretaceous and a covering of Quaternary débris save in that extreme southeastern corner included within the "driftless area" of Chamberlin.*

*See map and description in "The Driftless Area," etc, by T. C. Chamberlin and R. D. Salisbury, 6th Ann. Rep. U. S. Geol. Survey, 1885, pp. 205–322.

The lowest rocks considered in the following pages are referred to those now grouped as upper Cambrian. They will be discussed under two divisions, as follows:

2. The Magnesian series = the Lower Magnesian limestones of Owen;
1. The Potsdam sandstone = the Lower sandstones of Owen.

The next higher group described is that commonly referred to the Lower Silurian, including—

5. The Cincinnati;
4. The Trenton;
3. The Saint Peter.

The highest rocks of the region described belong to the Devonian.

Throughout the paper the rocks will be described in ascending order.

Résumé of earlier Investigations.

This portion of Minnesota has been a favorite excursion ground for the explorers of the Northwest since the time of Jonathan Carver. It was he who first attempted any description of the rocks of this area. He mentions that at the mouth of the Saint Peter river there exists a bed of sandstone whose color is as white as the driven snow.* Later Lieutenant Pike,† Major Long,‡ and Featherstonhaugh § visited the falls of Saint Anthony and many other places of geologic interest. The last-named writer was the first commissioned geologist who ever visited Minnesota, and while the compiler for Long's expedition made a section of the strata at Fort Snelling. Lieutenant Allen || described the bluffs of the lower Saint Croix from Stillwater to point Douglas, and J. N. Nicollet ¶ published many desultory notes on this region which were, however, chiefly geographic.

In the summer of 1839 David Dale Owen, of Indiana, received a commission from the secretary of the United States Treasury "as the principal agent to explore the mineral lands of the United States." His instructions directed him "to proceed to Iowa and undertake an explora-

*Travels through the interior parts of North America in the years 1766, '67 and '68: J. Carver, Esq., Dublin, 1779, p. 59.

†Pike, Major L. M.: An account of expeditions to the sources of the Mississippi and through the western parts of Louisiana, etc. Performed by order of the government of the United States during the years 1805, '6 and '7. Illustrated by maps and charts. Philadelphia, 1810.

‡Narrative of an expedition to the source of Saint Peters river, Lake Winnepeek, Lake of the Woods, etc. Performed in the year 1823 * * * under the command of Stephen H. Long, U. S. T. E. William H. Keating, 2 vols., London, 1825 (see p. 320).

§A canoe voyage up the Minnay Sotor, by G. W. Featherstonhaugh, 2 vols., London, 1847 (see chaps. xxvi–xxxvii, inclusive).

||American State Papers, vol. v, Military Affairs: Map and Journal of Lieut. J. Allen, in charge of escort accompanying Schoolcraft's expedition to the sources of the Mississippi. pp. 312-344.

¶Report intended to illustrate a map of the hydrographical basin of the upper Mississippi river, made by J. N. Nicollet February 16, 1841 (Senate Document 237, 26th Congress, 2d session).

tion of 'all the lands in the Mineral Point and Galena districts. * * * together with all the surveyed lands in the Dubuque district.'" He was further directed, as he says, "to select specimens of all the minerals of much value and to forward these to Washington city, as such a collection was deemed important to illustrate my official report, * * * and also interesting as forming the nucleus for a national cabinet."*

This fine observer and enthusiastic geologist, who labored so untiringly to extend our knowledge of the geology of the northwestern states, entered upon his labors in the upper Mississippi river valley. He lived long enough to see his work develop into at least three state surveys, several surveys under the United States government, and a magnificent national museum at Washington.

In the report cited,† Dr. Owen distinguished for the Northwest—

5. The recent deposits;
4. The Tertiary strata;
3. The Secondary strata;
2. The Primary fossiliferous strata;
1. Granite and other crystalline rocks.

Owen's more systematic work, however, was done on his return to this region in 1848 for more detailed geologic explorations. In his report of this work he distinguished the Paleozoic series—"The Primary fossiliferous strata"—in ascending order‡ as:

5. The Carboniferous limestones and coal fields of Iowa and Missouri;
4. The Cedar limestones (contemporary with the Devonian formation of the English geologists);
3. The Upper Magnesian limestones;
2. The Lower Magnesian limestones;
1. The Lower sandstones (the lowest protozoic strata).

The opinion was expressed that the Lower sandstones extend beneath the drift of the lake Superior country. Another opinion expressed by Dr. Owen must not here be omitted, since it was so accurate a prophecy: "There can now be little doubt that the whole mining region of the Mineral Point and Dubuque districts of Wisconsin and Iowa is based upon a syenitic and granitic platform, which would in all probability be reached by penetrating to the depth of from 2,000 to 4,000 feet."§ The artesian and other deep wells at La Crosse, Prairie du Chien, Mason City, Lansing and other points show the granitic floor to that distance southward to be less than 1,500 feet.||

*Senate Document 407, 28th Cong., 1st session, 1844, pp. 12, 13.

†Ibid., p. 15.

‡Report of a Geological Survey of Wisconsin, Iowa and Minnesota. Philadelphia, Lippincott, Grambo & Co., 1852: Introduction, p. xix.

§Ibid., p. 62.

|| Bull. Minn. Acad. Nat. Sci., vol. iii, no. 1, 1889, p. 135.

In March, 1872, under enactment of the legislature, the regents of the university of Minnesota were placed in charge of a geologic and natural history survey of the state. In that same year a state geologist was appointed, who has been working under somewhat limited appropriations to the present time. In order the more completely to carry out the intent of the law, the regents also appointed in 1888 a state zoologist, and in 1890 a state botanist. The publications of this survey thus far have been a series of annual reports, the nineteenth of which is now in press; several special bulletins; and two volumes of the final report, all of which are geologic except bulletins 3 and 4 and some special papers in the annual reports. Much is contained in the annual and final reports by N. H. Winchell, state geologist, and Warren Upham and M. W. Harrington, assistants, on the geology of the portion of the state discussed by the writers. Wherever use is made of this material reference will be made.

Finally, Warren Upham placed in the hands of one of the authors a manuscript which contained a syllabus of his observations in this portion of Minnesota up to the time of its preparation. It bore the date of May 5, 1883.

The upper Cambrian.

THE POTSDAM SANDSTONE.

The pre-Paleozoic Floor of the District.—The formations under consideration were laid down upon a floor of Archean and Algonkian rocks. This floor has been found below the Potsdam sandstone at Minneapolis, Stillwater and Brownsdale, and without doubt much if not all of the territory lying between those places and westward is underlain by the granitic and gneissic rocks. Probably three divisions of the Algonkian are represented. In the northeastern corner the Keweenawan diabases pass under the sandstones and shales around Taylors Falls and have been traced to Stillwater, where they lie 717 feet below the surface;* toward the north and northwest the schists and associated eruptive granites disappear beneath the feldspathic conglomerates of the Snake river; and along the western side of the area the quartzites and arenaceous shales of the red quartzite formation extend from Nicollet county southwestward into Iowa and South Dakota and were regarded as Huronian by James Hall † and Dr. C. A. White ‡ and subsequently by the Wisconsin geologists || and the members of the lake Superior division of the United States Geological Survey.§

* A. D. Meeds, Bull. Minn Acad. Nat. Sci, vol. iii, no 2, 1891, p. 274.

† Trans. Am. Philos Soc., new ser., vol xiii, 1866, p. 329.

‡ Geology of Iowa, vol. i, 1870, p. 171.

|| Geology of Wisconsin, vol. iv, 1873-'78, p. 575.

§ Irving and Van Hise, Bull. U S. Geol. Survey, no. 8, 1881, pp. 15, 34; C. W. Hall, Bull. Minn. Acad. Nat. Sci., vol. iii, no. 2, 1891, p. 218.

The basal Conglomerates of the Potsdam.—Everywhere so far as the basal beds of the lower sandstone, or Potsdam as it is generally called (following the suggestion of Professor James Hall in 1843),* have been seen they are strongly conglomeratic. The conditions prevailing in the formation of such basal conglomerates have been pointed out by Irving,† and indeed such beds are precisely what should be expected under the conditions actually obtaining in the northwest at that time: material broken from sea-cliffs and knocked about on the beach of a slowly sinking land area.

At Minneopa the boring of a deep well in 1888 showed a conglomerate lying between 575 feet and 800 feet below the surface. It was made up of well rounded pebbles of a vitreous quartzite, some of them very large, and many from one to three inches in diameter were thrown out during the boring. They were bound together by a fine red or reddish-yellow cement, which comes out of the well as an exceedingly clayey mud. The material of the pebbles is identical in every respect with the quartzites occurring from Courtland through Watonwan and Cottonwood counties into southwestern Minnesota and southeastern South Dakota. It is vitreous, non-granular, of varying texture and red color. A thin section shows the cementing material to be arranged crystallographically with the cemented grains and as enlargements upon them precisely as Irving and Van Hise ‡ have pointed out for the quartzites of Redstone (Courtland), the nearest area of these rocks to the Minneapolis well, and also as shown in a slide from the quartzite of Cottonwood county, Minnesota. The Minneopa well was sunk to the depth of 1,000 feet, but the record below 800 feet was thoroughly unreliable. §

On Snake river two miles above Mora there lies a bed of horizontal, cross-bedded conglomeratic sandstone. This exposure is less than three miles from the Ann river knobs of hornblende biotite-granite. The conglomerate has a cheerful light-pink color and is uneven in texture, the largest pebbles reaching a diameter of two or more inches. Many rounded pieces of feldspar are to be seen. The whole aspect of the rock is that of a clastic worn directly from the granites lying in the neighborhood. The pebbles are somewhat kaolinized, more so than are the granites of central Minnesota at the present time, a fact suggesting that the great bulk of the erosion which these rocks have undergone has been suffered since the beginning of Pleistocene time. Both Shumard || and

* Natural History of New York, part iv, Geology, 1843, p. 27.

† On the classification of the early Cambrian and Pre-Cambrian formations, R. D. Irving, Seventh An. Rep. U. S. Geol. Survey, 1886, p. 397.

‡ On Secondary Enlargements of Mineral fragments in certain rocks: Bull. U. S. Geol. Survey no. 8, 1884, p. 34.

§ Cf. Bull. Minn. Acad. Nat. Sci., vol. iii, no. 2, 1891, p. 250.

|| Owen's Geological Survey of Wis., Ia. and Minn., 1852, pp. 524, 525.

Upham* have observed the conglomeratic character of these deposits along Snake river.

Finally, at Taylors Falls in two or three places, one of which is near the crossing of the Saint Paul and Duluth railway at the entrance to the village and the carriage road running southward from the public school building, lies a continuous belt of very coarse conglomerate. The length of the exposure is twenty rods or more, and it is covered toward the southwest by the drift material pushed over the edge of the river gorge from the northwest. The same kind of a conglomerate, together with great cracked cliffs of diabase, whose crevices are filled with fossiliferous material, is to be seen on the Wisconsin side of the river at Saint Croix falls. Another bed is in the banks of the river between Taylors Falls and Osceola, Wisconsin. This conglomerate is made up of pebbles of diabase like the rock constituting the high, massive cliffs which along both sides of the river here form the picturesque "dalles" of the Saint Croix. They are dark colored; frequent fine examples of concentric weathering are seen, a peculiarity very common among the diabases of the lake Superior region. Some of the pebbles are very small, while others are of tons' weight. They are cemented together by a shaly magnesian sandsone carrying numerous cavities lined with crystals of dolomite, alternating with compact portions well filled with shells of *Lingulepis pinnæformis*, Owen; *Obolella polita*, Hall, etc. A typical locality of this conglomerate is represented by plate 11, figure 2, which is a photomechanical reproduction of the photograph taken from the western side of the carriage road entering Taylors Falls from the south.

Localities of the Potsdam.—In addition to the places just enumerated, this sandstone can be seen in strongly marked exposures along Saint Croix river from Taylors Falls to Marine, and in many localities in Winona, Houston and Fillmore counties along the bluffs of the Mississippi and its tributaries, particularly Root river and Rollingstone creek. In places this eroded formation produces the most conspicuous feature of the bluffs along the streams named. In the Minnesota river valley it does not appear as a surface formation, but it is reached in several wells.

Structural Characters.—The Potsdam sandstone appears to have been laid down in a great basin whose present rim is at the surface or beneath the glacial drift from Watonwan county, in southern Minnesota, northeasterly into Kanabec county, and from Chengwatona across the Saint Croix at the Kettle river rapids into Wisconsin, where it rests against the Huronian quartzites in Barron county and the gneisses and schists of Archean and Algonkian age, past Chippewa Falls, Black River Falls,

* The Geology of Minnesota, Final Report, vol. ii, 1888, p. 621.

Grand Rapids and Stevens Point.* On the southern borders, however, the rim of the basin lies beneath other and subsequent formations. The deepest known portion of this basin, is at Minneapolis, where granitic rocks have been struck at 2,150 feet below the surface. The slope of its bottom upward from this greatest depth is somewhat rapid toward the northeast, where Keweenawan diabases appear at the surface within 35 miles, and the northwest, where granite quarries lie within 50 miles in an air-line. Toward the south and southeast, however, the slope is more gradual, as granitic rocks have been reached at La Crosse about 500 feet below the Mississippi river.†

Throughout the entire thickness of this sandstone, which at Minneapolis is nearly 1,550 feet ‡ and at La Crosse 375 feet, are shown the ordinary structural variations of a great sandstone formation. In places a heavy conglomeratic character is observed; again a decidedly shaly condition prevails. While everywhere a stratified condition is seen, in some places this is much more marked than in others. It varies directly with the variation from the sandy to the shaly condition of this rock, being most complete with the latter, and is brought out beautifully when the rock is subjected to erosion or weathering. With the filling of this basin and the more rapid accumulation of sediments in its deepest portion a very level floor was formed at a quite uniform depth below the sea level, on which were laid down the dolomites and dolomitic shales of the great Lower Magnesian series of Owen, the Saint Lawrence, Magnesian and Shakopee of Winchell and Upham, with their interbedded sandstones.

Lithologic Characters.—The conglomeratic, arenaceous, calcareous and shaly phases of this formation have already been pointed out. In every locality where its rocks have been observed a friable condition is conspicuous. Yet at Hokah, Dresbach, Dakota, Stockton and one or two other places there is sufficient coherence or cementation to encourage quarrying; and, favorably for this business, the rock hardens on exposure. Occasionally this coherence is secured by the infiltration of a cement of silica or through the compacting and partial alteration of the rock itself, as at Dresbach and Dakota, but more usually through the infiltration of calcium carbonate from the overlying dolomites and the cementing together by it of the quartz grains. This condition is not so common in these rocks as in those of one or two beds above them and associated with the dolomites. It is not necessary here to give the anat-

*See General Geological Map of Wisconsin, 1881.

†From the records of the city engineer's office, La Crosse, through the courtesy of John James, Esq.

‡Bull. Minn. Acad. Nat. Sci., vol. iii, no. 1, 1889, pp. 125–143. The classification there used is essentially Warren Upham's as given in the manuscript cited (page 335). In this paper formations 11, 12, 13 and 14 (see pp. 134, 135 of the Bulletin named) are considered as one, and designated Potsdam.

omy of the individual grains constituting these quartzose masses, for they present the usual phases of silica as it appears in this type of rocks everywhere; they are externally well worn and of greatly varying size, from coarse conglomerates down to the constituent particles of the finest shale. In many places a green color becomes quite prominent. The cause of this has not yet been satisfactorily determined; the search for it is in its experimental stage by the authors with the hope of a demonstration in the near future. Here it appears to be due to ferrous oxide; there to a glauconitic mineral; again the conditions of a chlorite in thin, bright-green plates are fulfilled. The green constituent, in whatever phase it occurs, does not seem to possess any cementing quality; yet at Dresbach, Dakota, and even locally at Winona, there is a coherence far greater than is usual in Minnesota Paleozoic sands. At these places a fine white micaceous mineral is very generally present and is regarded as a kind of binding material. A shaly condition alternates with such sandstone in Winona county.*

Chemical Composition.—But little can be said touching the chemical composition of the Potsdam sandstone. Several years ago Mr. H. G. Klepper made an analysis of this stone from Lansing, Iowa, in the interest of glass manufacturers, with the following result:

SiO_2	62.93%
$CaCO_3$	19.04
$MgCO_3$	17.07
Fe_2O_3 } Al_2O_3 }	0.00
	99.04%

This certainly cannot be an average composition of the Potsdam sandstone of Minnesota.

Paleontologic Characters.—In fossil forms the Potsdam horizon is comparatively poor. At Taylors Falls several species have been noted, with fragments of at least three undescribed forms. The rock phases at this locality deserve mention in connection with the types of life preserved. The cementing material of the conglomerate is partly dolomitic rather than wholly arenaceous. The source of the carbonates must lie partly in the shells of the brachiopods and trilobites and partly in the decomposition products of the diabasic pebbles, for scarcely any of the finer ones remain. In percentage of MgO these diabases vary from 2.5 to 6.6, according to Mr. Sweet.† In secluded bays and inlets animal forms could find the protection from enemies and quiet seas and supply of food

*Cf. N. H. Winchell: Geology of Minnesota, Final Report, vol. i, 1884, pp. 257 et seq.

†Geology of the western Lake Superior District. E. T. Sweet: Geology of Wisconsin, vol. iii, 1880, p. 350.

which enabled them to flourish for hundreds of generations, until their remains had accumulated to the thickness of many feet. The small secluded bay at Saint Croix falls was especially adapted for the swarming of trilobites and lingulas beyond any other spot within the whole Minnesota Potsdam basin* thus far discovered. It would seem from the configuration of this basin that when the accumulations of shells had reached the depth at which currents were felt that the colony disappeared, since the overlying sandstones are quite destitute of animal remains.

The following is the list of fossils known to occur in the Potsdam:

Lingula ampla, Owen; *Linguiepis pinnæformis*, Owen; *Obolella polita*, Hall; two species of trilobites and one lingula still undescribed, all from Taylors Falls; other places have thus far shown:

Lingula mosia, Hall.
L. winona, Hall.
Obŏlella polita, Hall.
Orthis pepina, Hall.
O. remnichia, N. H. W.
O. sandbergi, N. H. W.
Bellerophon antiquatus, Whitf.
Holopea sweeti, Whitf.
Aglaspis barrandi, Hall.
Agnostus disparilis, Hall.
A. josepha, Hall.
A. paulis, Hall.
Amphion matutinas, Hall.
Dicellocephalus lodensis, Whitf.
D. minnesotensis, Owen.
D. osceola, Hall.
D. pepinensis, Owen.
Ellipsocephalus curtus, Whitf.
Illænurus quadratus, Hall.
Lonchocephalus chippewansis, Owen.
L. hamulus, Owen.
L. wisconsensis, Owen.
Menocephalus minnesotensis, Owen.
Ptychaspis granulosa, Owen.
P. minuta, Whitf.
P. striata, Whitf.
Ptychoparia anatina, Hall.
P. bidorsa, Hall.
P. diademata, Hall.
P. eryon, Hall.
P. explanata, Hall.
P. iowensis, Hall.
P. minuta, Whitf.
P. oweni, Hall.
P. perseus, Shu.
P. shumardi, Hall.
P. winona, Hall.
Triarthrella auroralis, Hall.

THE MAGNESIAN SERIES.

Subdivisions of earlier Writers.—This complex series, the Lower Magnesian of Owen, consisting of dolomites, shales and sandstones, was first described by that author in his geological survey of Wisconsin, Iowa and Minnesota.† Some conception of the complex character of these

*See Moses Strong, Geology of the upper Saint Croix District: Geology of Wisconsin vol. iii, 1880, p. 417 et seq.; also Warren Upham, Geology of Minnesota, Final Report, vol. ii, 1888, p. 408.

†1852, pp. 41–71.

rocks was foreshadowed in the writings of Keating and other explorers already cited.

N. H. Winchell in 1873 subdivided the series as follows, in ascending order:

3. Shakopee limestone;
2. Jordan sandstone;
1. Saint Lawrence limestone.

In 1883 Warren Upham, in his study of the geology of Blue Earth county,* was led to compare the stratigraphy of the Minnesota river valley with that of the Mississippi. In this comparison (in the manuscript referred to, on page 335, ante) the following series was determined:

5. Shakopee *A* limestone;
4. Elevator *B* sandstone;
3. Shakopee *B* limestone;
2. Jordan sandstone;
1. Saint Lawrence limestone.

The special item to note in the above is the discovery in Saint Paul, during the boring of a deep well at Elevator *B*, of a layer of sandstone 20 feet in thickness in the midst of the upper dolomitic member, the Shakopee. With some slight revising and a change in the names of two members of Upham's series, N. H. Winchell in 1887 adopted it and worked it out in considerable detail † as the most probable sequence of the magnesian for this state. The change consisted in adopting the name "New Richmond" for Elevator *B* and "Main body of limestone" for Shakopee *B*, a term for which "Lower Magnesian limestone" was subsequently used.‡

In the eleventh Annual Report of the United States Geological Survey W J McGee discusses § the nomenclature of this series. On account of the vagueness of Owen's descriptions, the obliteration by later investigators of the upper members as they were outlined by him (see ante, p. 334) and the practical abandonment of the series, Mr. McGee adopts the name Oneota for the middle member. Without tabulating, his classification is as follows: the Shakopee *A* and Elevator *B* beds are the lower portion of the Saint Peter of Iowa; the Jordan sandstone and the Saint Lawrence dolomite and shale are the upper Potsdam of that state; while the "Main body of limestone" (Upham's Shakopee *B*) is the Oneota, named after "the river upon which the rockmass finds its typical development." ||

*Geology of Minnesota, Final Report, vol. i, 1884, pp 415–453.

†Geology of Minnesota, Final Report, vol. ii, 1888, preface, p. xxii.

‡Ibid., pp. 12, 36, 72, etc.

§The Pleistocene History of Northeastern Iowa (op. cit., 1892, pp. 187–577). The authors desire to express grateful acknowledgments to Mr. McGee for his generous loan of proof pages of the article, so far as they referred to the Minnesota Paleozoic.

|| Ibid., p. 333.

From a comparison of McGee's clear statement of the Iowa Oneota and its contiguous rocks above and below with the Minnesota series as it is known to them, the authors feel that the alternation of sands, shales and dolomites which occurs in the latter state cannot well be considered as identical with the Oneota of Iowa. Paleontologic evidence, so far as it is at hand, bears testimony to the unity of the series between the Potsdam and the Saint Peter. Again, the structural, lithological and chemical identity of the beds is remarkable. An oolitic or a brecciated condition is not a marked feature of any one bed, but is found in all three dolomitic layers alike; the rhombohedral shape of the constituent grains is an almost universal character of the dolomites, and the chemical composition of any one layer can be duplicated in either of the others. These facts are equally true of the sandstones, so far as they will apply. The deposition in Minnesota was nearer the shore of the Cambrian sea, and thus exhibits all the phases of sediments from conglomerates through sands and shales to limestones, which in Iowa may not be the case. These different phases, for local purposes, must have different names. The awkward device "Main body of limestone," first used by Irving* and subsequently adopted by Winchell,† is shown by McGee to be awkward simply by the use of it in a geologic discussion. Besides the general and long-time use of the term Magnesian in Iowa, Wisconsin and Minnesota, a use which has firmly intrenched the word in our geologic literature and speech, with and without the qualifying words Upper and Lower, the dolomitic character of the rocks in question is most pertinently expressed in that word. Nowhere else on the North American continent have we such a vast extent of rocks carrying so typical a dolomitic composition as do the carbonate layers occupying the place between the Potsdam and the Saint Peter in our northwestern states. The terms Shakopee, Jordan and Saint Lawrence have been accepted for some years in Minnesota; their uses have been defined; the rocks are well known as a single group; accordingly in the present paper the term "Magnesian series" will comprise the following local members:

Magnesian series . . {
- Shakopee *A* (upper Shakopee) dolomite.
- Elevator *B* (New Richmond) sandstone.
- Shakopee *B* (lower Shakopee) dolomite.
- Jordan sandstone.
- Saint Lawrence dolomites and shales.

In the following discussion but little attention will be paid to these subdivisions; they are chiefly of local interest, since structural and lithologic characters are almost identical in all similar beds.

---

* Amer. Jour. Sci., 3d ser., vol. ix, 1875, p. 440.

† Geology of Minnesota, Final Report, vol. ii, 1888, p. xxii.

Localities of the Magnesian Series.—In the Minnesota river valley the rocks of this series extend continuously from Judson to Shakopee. Some exposures are at a distance from the stream and others lie in the banks of its tributaries, as along the Blue Earth; on the Saint Croix from the neighborhood of Marine to Point Douglas are many conspicuous exposures; on the Mississippi the most northerly masses are above Nininger and Langdon, whence they are continuous in a succession of rugged and castellated bluffs, usually capping the Potsdam, to the Iowa line; the tributaries of the Mississippi, the Vermilion, the Cannon, the Zumbro, the Whitewater, the Rollingstone and the Root present many faces of these rocks; and the sections of many artesian and deep wells throughout southern Minnesota.

Structural Characters.—Structurally, this series varies more than any other within the Paleozoic of the state. This arises from the varied character of the rocks. The dolomitic portions are massive, and form those striking scenic effects seen along the streams whose gorges are cut into or through them. Its thickness is considerable; its walls, through weathering and corrasion, have been gnawed away until they stand far apart and face each other with rugged, hoary and castellated fronts. Trickling waters have produced their effect in moulding the faces of these walls, or, as in the driftless area,* they have removed large masses of the rock, thus producing chasms, into which has fallen some débris. In this manner the many sink-holes have been formed which are to be seen on the otherwise smooth prairies of this area.

In many localities a brecciated condition is present in the dolomites—a condition not infrequent in Wisconsin, according to Chamberlin.† Ordinarily the chips composing this breccia are not large. In Winona county a brecciated structure characterizes much of the Saint Lawrence.‡ This even appears in some of the silicified material in the upper Shakopee. Another feature almost everywhere found in the central bed (the lower Shakopee) is a geodic and concretionary tendency. Silica is thus collected into segregations of great purity. Redwing and vicinity may be taken as a typical locality. In the dolomitic mass forming Lagrange mountain, now for some reason more popularly called Barn bluff, there are numerous segregations of a light gray microcrystalline silica, together with partial fillings which show cavities not infrequently of large size, with walls covered by sparkling facets of quartz crystals. In places these crystals are amethystine and of considerable size. An oolitic phase is

*The Driftless Area of the Upper Mississippi, Chamberlin and Salisbury, 6th Ann. Rep. U. S. Geol. Survey, 1885, p. 205.

†Geology of Wisconsin, vol. i, 1883, p. 140; vol. ii, 1877, p. 278.

‡Winchell, N. H.: Geology of Minnesota, Final Report, vol. i, 1884, p. 261: cf. Geology of Iowa, pt. i, 1858, p. 333.

very common, particularly in the uppermost layers of the Shakopee. This part of the Shakopee carries also that peculiar concretion designated *Cryptozoon minnesotense* by N. H. Winchell.* Many specimens have been found near Cannon falls, at Northfield, and between Mankato and Kasota they lie on the prairie in large numbers, weathered out of the rock. These concretions are associated with thickenings of the strata, gentle or strong foldings and a varying vesicular condition. Professor L. W. Chaney,† who has given some attention to these bodies, reaches the conclusion that their bulkiness is due to a concretionary accumulation. This, with the possibly more ready dissolution and removal of the non-concretionary intermediate portions, would account for the existing wavy condition of the strata.

The shaly condition is occasional in the upper Shakopee, although it is not a marked feature. It occurs in the Saint Lawrence, and is particularly shown in well borings from several towns. Indeed these borings show this member more frequently shaly or arenaceous than otherwise in the southwestern part of the area.

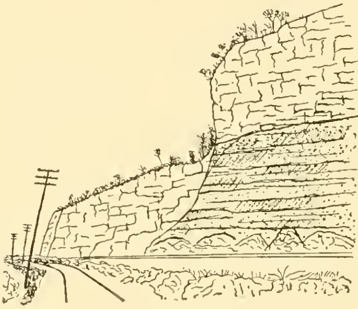


FIGURE 1.—*Fault in the Magnesian near Hastings, Minnesota.*

1 = Jordan sandstone, standing 30 feet above the railway tracks; 2 = lower Shakopee dolomite, which to the left of the fault is brought down to the level of the tracks and possibly lower. Sketched from a photograph by C. W. Hall.

Faulting among these magnesian beds is seen in several places. The most notable case is that near Hastings, on the eastern side of the Mississippi, beside the tracks of two railways, the Chicago, Milwaukee and Saint Paul and the Chicago, Burlington and Northern. The extent of slip cannot accurately be determined, but is not less than 50 feet. Figure 1, sketched from a photograph taken by one of the authors, shows the relation of the rocks distinctly seen from the railway trains. Without discussing the origin of these faults, the opinion may be expressed

*Geol. and Nat. Hist. Surv. Minn., 14th Ann. Rep., 1885, p. 313.
†Bull. Minn. Acad. Nat. Sci., vol. iii, no. 2, 1891, p. 280.

that the dolomitization of vast beds of Cambrian limestones and the consequent shrinkage in bulk is alone sufficient to account for the displacements.

The sandstones in all their phases have the usual characters of this rock. They may briefly be summed up as follows: Structure, massive and firmly bedded, with occasional shaly layers in local development; cross-bedding not infrequent; in places, indeed, very strongly marked; texture, varying through every condition from the conglomeratic to the finely comminuted; composition, varying somewhat from clear quartz by the occurrence of feldspathic and calcareous grains. A cemented condition of the grains in several counties furnishes a stone which is used for building purposes,* although such cementing is nowhere found to be at all extensive, and is no doubt due to an infiltration of carbonates from an overlying layer of dolomitic rock. The ferruginous appearance seen in places is due to infiltrated hydrous or anhydrous ferric oxide.

Lithologic Characters.—The sandstones may be described in few words. They are chiefly siliceous. Rarely, grains of other material than quartz are seen save at the bottom or the top of a bed. Within the beds themselves there is seldom any coherence. At the edges of the bluffs, where the carbonates have trickled down from above and cemented the grains, there is developed a tolerably firm rock, which has some economic value. Considerable coloring matter, particularly ferric oxide, is locally introduced. This is often the case in the Minnesota river valley, as at Ottawá, Lesueur, etc. In places spherical lumps and even huge botryoidal masses are formed in the upper sand layers by the trickling down of the carbonated waters. At Lanesboro and thence to Hokah, especially in the Jordan layer, these cannon-ball-like lumps weather out in profusion. When broken the fragments tend to assume a rhombohedral form through the cleavage of the calcite constituting the matrix. By breaking these spherical masses, surfaces several inches across can frequently be secured which exhibit in a beautiful manner the cleavage planes of calcite as they are held to the light. This is a very striking illustration of the strength and persistence of that crystallizing force which rebuilds broken crystals of the alums, vitriols, etc, for the chemist, enlarges the quartz fragments throughout whole beds of quartzite, extends hornblendes and augites in fragmental and eruptive rocks,† and produces the ophitic structure peculiar to many diabases. A kaolinic material appears in other places to be interstitial with the grains of quartz, precisely as in the Saint Peter sandstone above.

*Cf. N. H. Winchell: Geology of Minnesota, Final Report, vol. i, 1884, p. 253.

†C. R. Van Hise, Enlargement of Hornblendes and Augites in Fragmental and Eruptive Rocks: Amer. Journ. Sci., 3d ser., vol. xxxiii, 1887, p. 386.

The shales of this series are but little known. Well borings at Mankato, Blue Earth city and elsewhere show shales with but little crystallinity or coherence. They have a green color usually, which is possibly due to the presence of ferrous oxide. Everywhere they are partly made up of carbonates, with a liberal supply of quartz grains.

The dolomitic beds have certain characters of lithologic interest. Along the Mississippi river at Nininger, Hastings, Redwing, Frontenac and elsewhere a marked porous condition is frequent. It is more characteristic of the heavier layers. It is associated with concretions, with compact, finely granular streaks, and with changes in composition in such a way as to show undoubtedly the secondary origin of the dolomitic feature. Ordinarily the vesicular structure is not coarse, yet it is readily seen with the unaided eye. Locally the cavities are larger until a honey-comb structure appears, or even until the material is wholly removed and a cavernous condition results, with its recesses beautifully lined with stalactitic incrustations. These seem to be of pure calcite and are white. Streaks of a limonitic color occur in the rock. So far as they were examined, they were produced by the infiltration of ferric oxide, which stains the surfaces of the grains and rhombohedrons which build up the mass. As a rule, the compacter portions of the beds are of a much lighter gray color than the vesicular. Locally a greenish color pervades.

Microscopically there are two persistent characters visible throughout the series of specimens examined. The first is the rhombohedral form of the grains, manifested either in the external form of the individuals or in their internal cleavage, or in both respects. The external outline is, indeed, modified by the contact of neighboring particles, yet the beginnings of all the individuals are constantly under the laws of rhombohedral growth (see plate 12, figure 1, compact dolomite from Hastings). In the coarser phases of the rock this crystallized condition is even more pronounced than in the finer. In the vesicular portions not only is the rock itself in this condition, but the cavities are lined with the projecting angles of rhombohedra. Where the texture is coarse and the vesicular structure nearly wanting, numerous spaces occur where clusters of perfectly formed rhombohedra are gathered, and each figure has a border of transparent material whose condition strongly suggests calcite. Such a phase of the lower Shakopee occurs at Mankato, in the quarries of the northern portion of the city (see plate 12, figure 2). The sample was taken 25 feet above the Jordan sandstone. Again, a section taken from the old quarry at Frontenac, on the Mississippi river 10 miles below Redwing, shows the vesicular structure very pronounced. The rhombohedral outline of the individuals is clearly defined, and by a seg-

regation of impurities a distinct tendency to an oolitic structure is foreshadowed (plate 12, figure 3, is from a slide prepared from this Frontenac dolomite). The rock from the new quarry at the same place has a more compact structure, a finer texture, and a lighter color. The determination of purity has not been made by chemical analysis of the specimens from these two quarries. All the compact and vesicular phases that have been noted can be seen at scores of places among the many exposures of these dolomites.

The brecciated condition of these rocks and the oolitic phase, which is also seen, have both been mentioned. Slides prove only the more clearly what can be seen with the unaided eye in these phases. The angular fragments which have been thrown together in the breccia show many differences in texture and in mineral composition; some of them have quartz grains, others are very fine. The oolitic structure seems to be due to a molecular or chemical readjustment of the material. But the siliceous oolite shows certain points of interest in addition to those just named. While many specimens have been seen from different depths in this series, the most common occurrence is at the top of the upper Shakopee. Large masses of microcrystalline silica are found segregated in these dolomitic layers. It appears that frequently rounded grains of quartz serve as nuclei around which the silica coming down from the overlying sands gathers in crystallographic continuity, building out to a considerable size these small grains, and then becoming imbedded in a matrix of microcrystalline (chalcedonic) silica (see plate 12, figure 4). These masses of oolite were doubtless formed in the same way as were the segregations of silica so frequently met with, notably at Stillwater, Redwing and Winona, only here there are nuclei around which the silica can arrange itself, while there a deposition on surfaces, within cavities, and along crevices presents a microstructure partly chalcedonic and partly agatoid. Thin sections show very beautiful and intricate microgranular growths.

Chemical Composition.—In chemical composition the dolomites as a group show a heavy proportion of impurities, particularly silica. When these impurities alone are considered, there is seen to be considerable variation in the composition of the beds; when the carbonates are considered, the variation from a typical dolomite, that is, a rock in which $CaCO_3 : MgCO_3 = 1 : 1 = 54.4 : 45.6$, is no more than would naturally be expected in a rock series underlying many thousand square miles. The variation alluded to is based on the quantity of these two carbonates in the rock to the exclusion of all other constituents; $MgCO_3$ is not pitted against the field, as in some instances is the case.

Below are given some analyses of these dolomites. A large part of them have been made in the chemical laboratory of the university of Minnesota. Those starred (*) were made especially for this paper.

	I.*	II.*	III.*	IV.*	V.*	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
$CaCO_3$	47.96	46.46	47.22	44.78	54.34	50.46	40.00	....	58.65	48.30	51.40	44.68	46.86	48.74
$MgCO_3$	44.45	48.92	37.50	34.26	41.09	36.26	31.50	....	29.15	36.80	40.70	31.59	33.56	29.27
$FeCO_3$	1.41	....	0.73	0.59	0.79	....	....	....	....	....	....	....	....	....
SiO_2	5.15	1.75	13.01	18.96	1.84	8.58	16.00	16.24	†7.25	†6.90	trace	15.50	12.10	13.39
Al_2O_3	1.13	0.43	1.31	1.09	0.85	3.18	5.85	5.35	*1.55	*4.30	*4.60	3.72	2.99	4.17
Fe_2O_3	....	....	....	....	....	1.72	2.73	4.71	....	....	....	2.43	2.65	1.52
Na_2O	....	....	....	....	....	trace	0.54	0.57	....	....	....	....	....	0.25
K_2O	....	....	....	....	....	trace	0.22	1.81	....	....	....	....	....	0.26
H_2O	....	....	0.21	0.37	0.03	....	0.43	0.51	2.65	‡3.70	‡3.30	....	....	....
CaO	....	....	....	....	....	....	....	38.53	....	....	....	0.09	0.05	....
MgO	....	....	....	....	....	....	....	22.73	....	....	....	0.04	0.02	....
CO_2	....	....	....	....	....	....	....	9.26	....	....	....	....	....	....
	99.30	97.56	99.98	100.05	98.94	100.20	97.27	99.77	99.25	100.00	100.00	98.05	98.23	97.60

I. Compact dolomite, Dresbach; analyzed by C. S. Chapple.
II. Compact dolomite, Nininger; analyzed by Mary E. Bassett.
III. Dolomite, bottom layer quarried at Mankato; analyzed by C. L. Herron.
IV. Dolomite, buff-colored Kasota stone, Kasota; analyzed by H. C. Carel.
V. Dolomite (porous), Frontenac; analyzed by J. G. Cross and E. P. Sheldon.
VI. Dolomite, Ottawa; analyzed by Professor J. A. Dodge.
VII. Dolomite (cement rock), Mankato; analyzed by Professor C. F. Sidener.
VIII. Cement manufactured from Mankato cement stone; analyzed by Professor C. F. Sidener.
IX. Dolomite; reported by B. F. Shumard, Owen's Geol. Wis., Ia. and Minn., p. 484.
X. Dolomite, lake St. Croix, below Stillwater; reported by B. F. Shumard, Owen's Geol. Wis., Ia. and Minn., p. 59.
XI. Dolomite, Gray Cloud island; reported by B. F. Shumard, Owen's Geol. Wis., Ia. and Minn., p. 59.
XII. Dolomite, section 20, Lime; analyzed by Professor J. A. Dodge.
XIII. Dolomite, quarry of Maxwell and Mather, Mankato; analyzed by Professor J. A. Dodge.
XIV. Dolomite, "cement rock," Mankato; analyzed by W. C. Smith.

Paleontologic Characters.—The fauna of the Magnesian in Minnesota, so far as reported, is very meager. This is due in part to the imperfect manner in which fossils are preserved and in part to the fact that systematic search in these unpromising beds has rarely been attempted. However, specimens from this series have been incidentally found by the authors and by others; and it seems probable that a large fauna could

* "Alumina, oxide of iron and manganese."
† "Insoluble matter."
‡ "Water and loss."

be worked out. Crinoids, brachiopods, gasteropods, cephalopods, lamellibranchs, crustaceans, etc, have been found. In the Shakopee, numerous specimens of *Cryptozoön minnesotense*, N. H. Winchell, occur both in Minnesota and Wisconsin, but it is doubtful whether these should be included as fossils on account of the difficulty of showing their organic origin and of distinguishing them as they occur from merely folded strata between which and the concretion-like *Cryptozoön* there seems to be every degree of gradation.

The Lower Silurian.

CLASSIFICATION OF THE GROUP.

In its area and in the thickness and massiveness of its rocks this group is greatly subordinate to the upper Cambrian in Minnesota; yet in paleontologic interest it stands preëminent. Structurally and lithologically it is divided into limestones and shales. While these subdivisions are sufficient for ordinary economic purposes, they are of no scientific value; nor can they be, since they not only merge into one another but both the limestones and the shales are very far removed from any type both in physical character and chemical composition. A collection of fossils such as lies before us, collected and arranged with much care, develops the following classification of the formations:

Lower Silurian	Cincinnati	Wykoff.	(Not subdivided.)
		Maquoketa.	(Not subdivided.)
	Trenton ...	Galena	*Maclurea.*
			Lingulasma.
			Camarella.
			Orthisina.
		Trenton ...	*Zygospira.*
			Fucoid.
			Stictopora.
			Stictoporella.
			Blue limestone.
			Buff limestone.
	Saint Peter.	(Not subdivided.)	

In Minnesota the Saint Peter consists of sandstones; the Trenton and Cincinnati of limestones and shales. So far as known to the writers, Mr. E. O. Ulrich was the first to apply the name "Trenton shales" to the extensive series of calcareous shales occupying the upper part, from *Stictoporella* to *Zygospira*, inclusive, of the division Trenton of the third column above.

THE SAINT PETER SANDSTONE.

Localities.—There are no exposures of this formation in the Minnesota river valley except within two or three miles of the mouth of that stream and beneath the walls of fort Snelling, where the name was originally given (see ante, page 333); along the Mississippi from Minneapolis to Newport, on both sides of the river; along Straight river at and near Faribault and northward from that city in the banks of Cannon river; at Castle rock, Farmington, Hampton and New Trier in several outliers; near Cannon falls; around Pine island; at Saint Charles and vicinity; in many bluffs along the streams in Houston, Fillmore and Olmsted counties, particularly at Preston and Fountain.

Structural Characters.—This formation is throughout so extremely friable that it owes its preservation to the protection of the overlying Trenton limestone. As a consequence it plays quite an important part in moulding the topographic features of those counties where it occurs; streams and underground waters erode it with great rapidity. The rock is so friable that blocks will not sustain their own weight in handling, except those taken from the very edge of the exposure, where an infiltrated cement of calcium carbonate binds the rounded and smooth quartz grains together. In such places considerable use can be made of it for building purposes, bridge construction, etc, as has been done at fort Snelling. There is considerable diversity in texture, considering the formation as a whole, yet more uniformity is seen here than in the Potsdam sandstone or in the interbedded sandstones of the Magnesian series. In Olmsted and Fillmore counties the texture is much coarser than in Hennepin and Ramsey counties, as well as more uneven.

In much of its thickness the bedding of this sandstone is very obscure. Frequently bluffs show many feet where a close inspection is needed to distinguish the lamination. Cross-bedding and slight color alterations are seen. Here and there bright colors are shown in bands and tortuous streaks, as at Minnehaha falls, but no such strong color contrasts have been noted as are displayed in the sandstones of this formation southward in Iowa.* Locally, some tendency to a shaly condition appears, particularly at Highland park and near south Saint Paul. At the last-named place the lamination is so distinct that, where the layers have been undermined in securing moulding sand, sheets ten feet or more in length can be split off from the overhanging sandstone roof. The position of the laminæ here, as everywhere in the state where observed, is

* W J McGee, Pleistocene History of Northeastern Iowa: 11th Ann. Rep. U. S. Geol. Survey, 1892, p. 330.

horizontal, barring some slight undulations due to fissures and faulting lines.

Lithologic Characters.—Owen says of this sandstone, "At most of the localities where it has been observed it is remarkable for its whiteness."* This white color is due to the condition of the surfaces of the grains; they are worn simply to a dead finish—not polished, as can readily be seen by immersing them in water, when they become limpid. Its white color is its preëminent character throughout Minnesota. Locally it is stained red, brown, pink and even green through the infiltration of ferric oxide, the particular color being due to the quantity or condition of this oxide. Nowhere is there enough to make a pronounced change in the chemical composition of the rock. Another element of impurity in this rock, particularly within the Saint Anthony area, is fine, white kaolin. Sometimes there is sufficient to render quite turbid the water in a test-tube in which a spoonful of the sand has been poured. Possibly the presence of this argillaceous matter coating the smooth quartz grains prevents the cementation which would convert a clean sand into a quartzite.†

In speaking further of its purity and fitness for glass-making, Owen states that an analysis gave but two-tenths of one per cent of foreign matter, which is alumina, with a trace of carbonate of lime.‡ One of the writers several years ago made an examination of the rock at Minneapolis and found 98.50 per cent silica and the balance made up chiefly of alumina; and Professor Dodge, of the university of Minnesota, found the iron oxide of this Minneapolis rock to amount to only 17 hundredths of one per cent. Both samples were taken from the unstained layers, since they were made in the interests of glass manufacture.§

Mr. Julius Hortvet has recently analyzed the fossiliferous sandstone of south Saint Paul for this paper with the following result:

$Si\,O_2$	99.78 per cent.
$Fe_2\,O_3$	trace.
$Mg\,O$	trace.

Ca, Na and K were detected by spectroscopic tests. This result is almost identical with that of Owen already cited.

In texture this sandstone is somewhat coarser in its bottom layers than in the middle and upper ones. This seems to be the case at Cannon falls and Northfield, although nowhere was a conglomeratic texture

* Geol. Survey Wis., Ia. and Minn., 1852, p. 69.

† A. Geikis says: "It is owing, no doubt, to the purely siliceous character of the grains that the blending of these with the surrounding cement is so intimate that the rock often assumes an almost flinty homogeneous texture."—Textbook of Geology, 1st ed., 1882, p. 127.

‡ Ibid, p. 69.

§ Bull. Minn. Acad. Nat. Sci., vol. iii, no. 1, p. 113.

noted nor a mixture of dolomitic pebbles torn from the underlying Magnesian, as is the case in Wisconsin.* The outliers of this sandstone at Chimney rock, in Marshan township, and at Castle rock, both in Dakota county, show some strong color markings due to infiltration, and they show strong cross-bedding and in places a distinct lamination. The different degrees of hardness of the layers induce the interesting sculpturing which gives name to these exposures, whose existence is doubtless due to the presence until recently of a cap of Trenton limestone.

Paleontologic Characters.—The fauna of the Saint Peter has until recently been almost unknown. In Wisconsin in 1873 and 1874 Chamberlin found scolithus tubes and fucoidal impressions † at Beloit and Waterloo. In 1875 N. H. Winchell found *Lingulepis morsensis* ‡ (which name was subsequently changed to *Lingula morsei* by S. A. Miller); and in 1884 N. H. Winchell also recorded the presence of circular pits in the sandstone at Faribault and Castle rock.§ The writers also have noted these borings, and on exploring them have found larvæ casts; moreover, these tubular markings have not been noted in fresh deep exposures; hence the fossil nature of the borings is regarded with some suspicion. One year ago one of the writers discovered quite a number of fossils in a small railway cut near Highland park, on the Chicago, Burlington and Northern railway, a few miles from Saint Paul; these fossils comprised several genera and species already recognized.|| During the present month (December), at a cut between the Chicago, Saint Paul and Kansas City railway shops and south Saint Paul, fossils were found in large numbers, all comprised, however, in three or four species. The sandstone in which these last fossils were found is almost pure white. Chemically it is nearly pure silica. It was this fossiliferous rock that Mr. Hortvet analyzed with the result given on a preceding page. In both localities the shells are wholly absorbed. At Highland park a stain of ferric oxide covers the walls of the casts; yet the growth markings are distinct. Near south Saint Paul the walls are perfectly smooth and show distinctly muscle impressions, as well as growth striæ. These markings are easily obliterated with careless handling, owing to the extreme friability of the rock. The study of this newly discovered fauna is in progress; yet enough is already known to show that it is thus far almost wholly molluscan. *Murchisonia gracilis*, Hall, *M. perangulata*, Hall, with four other gasteropods; two new species of *Modiolopsis; Tellinomya*, sp. undet.;

* Chamberlin: Geology of Wisconsin, vol. ii, 1877, p. 287.

† Ibid., p. 288.

‡ Geological and Natural History Survey of Minnesota, Ann Rep. for 1875, p. 41.

§ Geology of Minnesota, Final Report, vol. i, 1884, p. 656.

|| F. W. Sardeson: Fossils in the Saint Peter Sandstone. Bull. Minn. Acad Nat Sci., vol. iii, no. 3, 1892, p. 318.

and *Endoceras*, sp. undet., are among the specimens obtained. They show the distinctively Lower Silurian character of the Saint Peter sandstone.

Physical Relations.—There are some points in the structural characters of this formation which lead the authors to regard it as a transition bed between the Cambrian and Silurian periods.

1. In the first place, the Wisconsin geologists have proved that for many localities the Lower Magnesian is an eroded formation. This erosion represents within their area a period of cessation in the deposition of rock material. Several of them have described the conditions observed and have in several figures represented the unconformity of the Saint Peter upon the Lower Magnesian—*i. e.*, Cambrian. T. C. Chamberlin, in his report on the geology of eastern Wisconsin, mentions places where

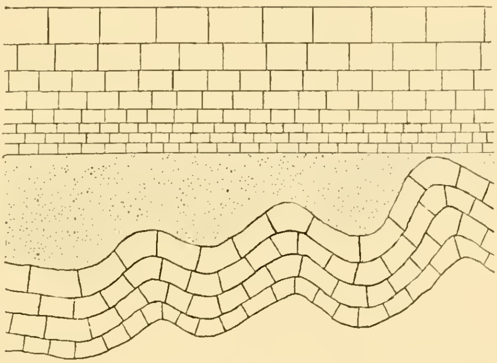


FIGURE 2.—*Unconformity of the Saint Peter on the Magnesian and the Conformity of the Trenton on the Saint Peter* *

1 = Magnesian; 2 = Saint Peter; 3 = Trenton.

the former lies upon the eroded edges of the latter, and in instances cited its upper surface is many feet below the crests of the Lower Magnesian ridges.† He also cites localities where the Saint Peter is wholly wanting and the Trenton, which has been preserved throughout the erosion which this region has subsequently undergone, lies directly upon the Lower Magnesian.‡ No such evidence as this has been found in Minnesota thus to establish the boundary between the Cambrian and Lower Silurian at the base of the Saint Peter. On the contrary, this formation is everywhere found in thickness varying from 75 § to 164 feet beneath the Trenton.

* Diagrammatic section from Chamberlin, Geol. Wis., vol. i, 1882, p. 145.

† Geology of Wisconsin, vol. ii, 1877, p. 271.

‡ Ibid., p. 285.

§ N. H. Winchell: Geology of Minnesota, Final Report, vol. i, 1884, p. 219.

One of the authors while collecting lower Paleozoic fossils in southern Wisconsin had occasion to note quite closely the relations of these formations now under consideration. His observations convinced him that the Lower Magnesian was folded locally into a succession of ridges and depressions. Every character showed this folding to be due to lateral pressure. The structural appearance, the uneven character of the folds, and the parallelism of the lamination of the rock and the configuration of the Saint Peter strata on the dolomite beneath, all pointed to that cause. The laminæ of the two formations were perfectly conformable. The conclusion is that *the folding of the Magnesian extended upward and involved the Saint Peter.*

The conditions above cited were seen in the Pecatonica valley, between Blanchardville and the Wisconsin-Illinois boundary, at several different localities; and a similar folding of the Magnesian has already been mentioned as occurring at Northfield, Minnesota.

2. Considering now the Saint Peter alone, we note that at south Saint Paul it shows many minor faults. In regrading a street from the Chi-

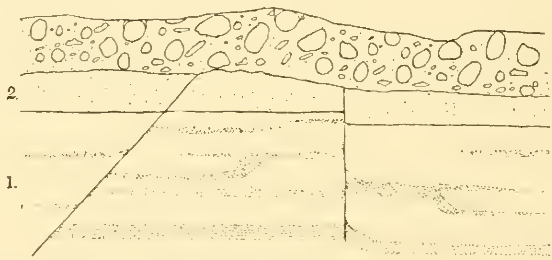


FIGURE 3.—*Minor Faults and Color Markings of the Saint Peter Sandstone at south Saint Paul.*

1 = Normal Saint Peter sandstone, colored along lines of bedding; 2 = Saint Peter sandstone, colored and cemented by infiltrations from above, and covered by a layer of river gravel mingled with bowlders.

cago, Saint Paul and Kansas City railway shops to the south Saint Paul packing-houses considerable cutting has been done in the side of the sandstone bluff along which the street extends. These fresh exposures, a quarter of a mile or more in length, afford an excellent opportunity to study the structural features of the middle portion of this formation. These faults are of interest, too, in that they occur in almost incoherent sands, just as clearly defined as in the firmer and more sharply laminated beds. The faults are sometimes vertical, yet oftener inclined in various directions, prevailingly north and south. Figure 3 sketches these faults.

3. In the third place, at a number of localities, particularly within the Saint Anthony area, opportunities are afforded for studying the contact

of the Saint Peter sandstone and the Trenton limestone. Nowhere is there any indication, however slight, of an unconformity. The transition zone of a green shaly calcareous sandstone shows the steady oncoming of that Lower Silurian sea which, if it did not submerge the whole Northwest, at least extended so far that the dry land was reduced to islands or narrow peninsular stretches of very uncertain connection with a mainland lying somewhere. For a considerable distance below this contact zone the sandstone shows no such faulting or jostling of the strata as can be seen in the spot already mentioned, estimated to be from 75 to 90 feet from its base. The same may be said of the exposures of the Saint Peter in the southern area, notably at Cannon falls, Faribault and Fountain, where the beds are exposed for a considerable distance from the top downward.

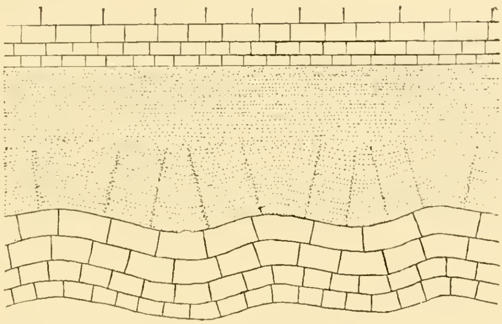


FIGURE 4.—*Diagrammatic Sketch showing the Relations of the Magnesian, Saint Peter and Trenton.*

1 = Magnesian with gentle folding; 2 = Saint Peter folded with the Magnesian in its bottom layers and displaced by faults, which extend upward but disappear before the top is reached; 3 = Trenton (Buff) limestone conformable with the Saint Peter.

From the three considerations pointed out we conclude that this sandstone, which geologically occupies so important a place in Michigan (?),* Wisconsin, Minnesota, Iowa, Missouri and Illinois, represents, for Minnesota at least, a great transition epoch between Cambrian and Lower Silurian time. It stands for the interval between the close of the deposition of those rocks which are now dolomites, whatever they once might have been—an interval which in eastern Wisconsin was one of dry land and erosion,—and that succeeding period of long-time permanent Silurian seas with their varied fauna and well defined flora.

These physical conditions and the faunal characters recently discovered seem to us to place beyond all question the Saint Peter sandstone of the northwestern states in the column of Lower Silurian epochs, and

*Geology of Wisconsin, vol. i, 1877, p. 149.

for these states at the very base of that column. This relation is shown in figure 4.

It may further be said that the Saint Peter was involved with the remainder of the Lower Silurian in the movements which brought about the gentle minor undulations seen in the latter at many places in southeastern Minnesota, and in the major wave whose crest is shown on the profile drawn at the bottom of the map (plate 10) accompanying this paper.

THE TRENTON LIMESTONES AND SHALES.

Localities.—In many different townships of Fillmore and Olmsted counties, at Saint Charles and Clinton falls, around Faribault, near Elgin, at Cannon falls and southward to Kenyon, at Berne, Old Concord, Belle creek, Farmington and Mendota, in several outliers in Washington county, and at numerous places in the cities of Minneapolis and Saint Paul, the Trenton rocks occur.

For convenience in description, the foregoing localities will be grouped in two areas, viz, the Saint Anthony area and the Southern area. The former comprises those exposures of Lower Silurian rocks within twenty miles or so of Saint Anthony falls, where the Mississippi breaks over the shelf of Trenton limestone almost at the northern limit of the formation: while the latter includes all those exposures within the state south of Hastings and Farmington. This is, in the area underlain by its rocks, by far the more important of the two.

Structural Characters.—These characters are extremely varied. There is almost every phase of a stratified rock from a compact massive limestone to a thinly laminated, fissile, carbonaceous shale. They will be chiefly considered in connection with the paleontologic characters of the different beds into which the representative fossils appear to divide the formations. Here, however, it may be stated that, resting upon the green and somewhat shaly top of the Saint Peter, there lies in a stratum of some inches in thickness, but with no well defined upper boundary, a blue-green-gray finely textured rock which lacks adhesion to such an extent as to crumble and become worthless. The limestone above contains numerous interrupted layers of this crumbling material. These layers cause the rock to separate easily on exposure, thus becoming an inferior building stone unless laid in the same horizontal position as they occupy in the quarry. Many joints occur, and sometimes they can be traced hundreds of feet. Only one or two cases of faulting are known.

Lithologic Characters.—A discussion of these will be restricted largely to the more compact lower layers, since the shales are very difficult to

section by reason of the generally uniform composition and structure throughout and the absence of well defined and constant stratigraphic elements.

The lower contact zone just mentioned gives in part areas of calcium and magnesium carbonates and in part clusters of kaolinic material and grains of quartz. The general aspect is that of a rock whose original characters have become in great part obscured by infiltration of new material.

The next layer above this contains bands of quite pure calcium carbonate often several inches thick. Scattered through these bands are occasional clusters of pyrite and granules of carbonaceous matter. The argillaceous bands which alternate with these show a finely crystalline granular matrix, in which lie rhombohedrons of calcite (see figure 5, plate 12). This layer readily crumbles on exposure to the air, causing the compacter limestone bands to separate. The chemical composition of this layer and that of other portions associated with it will soon be given, when conditions will be seen which explain the crumbling and great lack of cohesion which the rock presents. The layer above this fails to show the banded character just mentioned, but its proportion of alumina, silica and ferric oxide is also very marked. Within it pyrite often becomes clustered in quite large nodules, and the cavities from which the fossils have been absorbed contain on their walls incrustations of beautiful calcite and pyrite crystals, both single and clustered. Well developed rhombohedrons also characterize many portions of this layer.* Nowhere have the writers observed the presence of twinning in these rhombohedrons, although cleavage is usually distinct.

Chemical Composition.—This has always been a matter of great interest to those who have examined the formation Owen, who called the Trenton the "Saint Peter's shell limestone" from its richness in organic remains, stated that the lowest bed contained 65 per cent $CaCO_3$ and 13 per cent $MgCO_3$ and pronounced it a poor hydraulic limestone.† Many analyses have been made in the chemical laboratory of the university of Minnesota. These analyses represent particularly the layers which have some economic value, especially for building stone, for which the rocks of the lower calcareous division of the formation are largely used. The following table contains those of present interest:

*C. W. Hall, Lithological characters of the Trenton limestone, etc: Bull. Minn. Acad. Nat. Sci., vol. iii, no 1, 1889, p. 118.

†Geology of Wisconsin, Iowa and Minnesota, 1852, pp. 71, 72.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
$CaCO_3$	79.18	83.24	56.47	28.86	80.60	77.21	36.40	70.53
$MgCO_3$	6.38	5.40	14.21	11.18	18.00	3.91	0.40	23.49
CaO combined with SiO_2	trace	0.13	trace	......	......	......	......	......
MgO combined with SiO_2	0.04	trace	0.14	......	......	......	......	......
SiO_2	8.16	5.79	15.84	20.38	1.30	9.99	*29.00	4.57
Al_2O_3	2.67	2.04	4.93	26.77	1.30	3.43	12.40	......
Fe_2O_3	†2.43	†1.89	†4.00	†15.31	1.20	2.69		0.73
K_2O	trace	trace	trace	......	......	......	......	......
Na_2O	trace	trace	trace	......	......	......	......	......
Organic matter	0.80	0.46	1.26	......	......	......	......	......
H_2O	......	......	......	......	trace	1.91	‡18.00	......
Total	99.66	98.95	96.85	102.50	102.40	99.14	96.20	99.32

I. The Buff limestone; the rock analyzed as a whole. Professor J. A. Dodge, university of Minnesota.

II. The Buff limestone; the clean calcareous portions with the dark alumino-siliceous bands removed. Professor J. A. Dodge.

III. The Buff limestone; the dark alumino-siliceous bands with the calcareous portions removed. Dr. W. A. Noyes.

IV. The lower strata of the Blue limestone; those that crumble on exposure to the air. Horace V. Winchell.

V. The Buff limestone. Miss M. L. Blanchard.

VI. The Buff limestone. W. A. Beach.

VII. The lower (first) strata of the Blue limestone; probably the same as IV. Dr. Norwood.§

VIII. Galena limestone; section 9, Spring Valley. Chemist unknown.

Paleontologic Characters: The general Section.—In presenting these characters of the Lower Silurian rocks (aside from the Saint Peter, already briefly described) many structural features must be detailed which for this very reason were omitted from the paragraph purporting to outline those characters. Furthermore, many facts will be presented which have been discussed more in detail in another place.|| The names here given to the second beds are those proposed in the article referred to.

So far as observed, the lowest Trenton bed of the state, the Buff limestone (lower Buff of the Wisconsin series),¶ rests conformably on the Saint Peter, save at Faribault, Rice county, where the bed is absent, thus bringing the Blue limestone upon the sandstone and in conformable position. From this point up to the top of the Silurian series for the state there has not been seen either break or unconformity, though the

* Insoluble silicates.

† Fe_2O_3 and FeO calculated together.

‡ Loss, 3.80 per cent, also reported.

§ Geological Survey of Wisconsin, Iowa and Minnesota: Owen, 1852, p. 72.

|| The range and distribution of the Lower Silurian Fauna of Minnesota, etc, by F. W. Sardeson: Bull. Minn. Acad. Nat. Sci., vol. iii, no. 3, 1892, pp. 326–343.

¶ Geology of Wisconsin, vol. i, 1883, p. 162.

beds vary somewhat in thickness and dip in certain localities. The dip of these rocks in Minnesota is not uniform over any large area, but weak anticlinals and synclinals are frequent. The Galena dips several degrees toward the south in the quarries near Owatonna; in the quarry at Kenyon there is a marked synclinal and at Faribault a slight dip; at Cannon falls (in N. E. ¼ sec. 31, T. 112, R. 18 W.) the beds of the Galena are so much below those of a neighboring lower horizon (in sec. 29, same township) as to be confusing unless lithologic and paleontologic data are relied upon. The Lower Silurian in Minnesota is undulating as in Wisconsin, only not in so strong folds.

The following is a summary description of the several beds (figure 5):

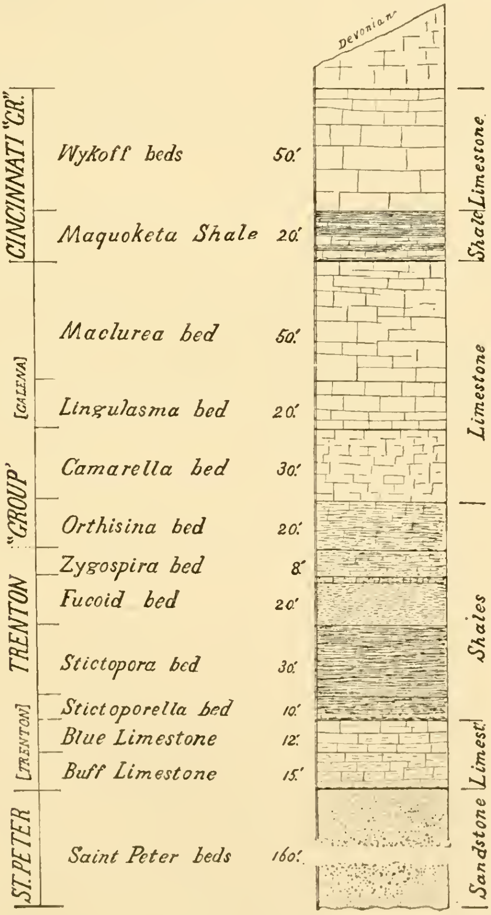


FIGURE 5.—*Classification of the Lower Silurian.*

A vertical section representing the relative thickness of the several beds, their lithologic characters and their distinctive faunal types.

The Buff Limestone.—This is 15 feet thick. It has the constant character of being made up of somewhat irregular laminæ, usually composed of alternating hard, firm limestone and softer, darker colored argillaceous bands. The action of percolating waters may render these strata porous by removing the more soluble parts. On the other hand, it may render them more crystalline by their metamorphosing effect on those constituents remaining behind. In the former case fossils are reduced to mere casts and cavities; in the latter they are entirely destroyed. At Minneapolis this layer preserves more fossils than it does further southward.

The following fossils occur in this bed:

Crania trentonensis, Hall.
Leptæna sericea, Hall.
Orthis deflecta, Conrad.
O. perveta, Conrad.
O. tricenaria, Conrad.
Rhynchonella orientalis, Billings.
Skenedium anthonensis, Sardeson.
Streptorhynchus filitextum, Hall.
Strophomena minnesotensis, N. H. Winchell.
Zygospira aquila, Sardeson.
Cypricarditis rotundatus (?), Hall.
Modiolopsis meyeri, Billings.

The Blue Limestone.—This layer is 12 feet thick. It lies directly upon the Buff limestone just described, save at Faribault. The two beds

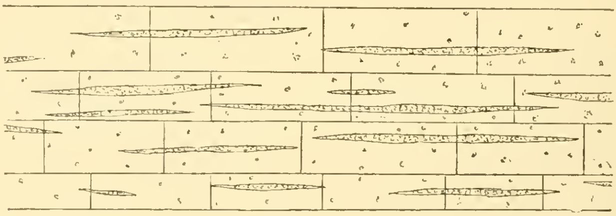


FIGURE 6.—*Lenticular Segregations of Fossils in the Blue Limestone, Minneapolis.*

The lenses represent the deposition of vast numbers of fossils within restricted areas. The shells have totally disappeared, leaving only casts of the interiors.

are separated by a distinct change in rock texture and usually, though not always, by a carbonaceous seam. The Buff separates along laminæ determined by the argillaceous bands; the Blue lies in heavy strata which break in all directions with a conchoidal fracture. The lower half is more crumbling when exposed and presents few fossils save in lenticular horizontal seams. These seams show how the fauna dwelt in colonies. For one or three inches in depth and stretching out over 100 or 200 square feet, the rock is wholly made up of casts of fossils whose surfaces carry coatings of calcite and pyrite crystals, while the rock for some distance above and below shows scarcely a trace of fossils (see figure 6). From the very uppermost stratum a few well preserved shells

weather out. Rarely the Blue and the Buff beds become somewhat alike lithologically through the effect of destroyed fossils.

The fossils of the Blue limestone are—

Crania trentonensis, Hall.
Discina concordensis, Sardeson.
Lingula elderi, Whitfield.
Lingulella iowensis, Owen.
Orthis bellarugosa, Conrad.
O. deflecta, Conrad.
O. perveta, Conrad.
O. tricenaria, Conrad.
Rhynchonella minnesotensis, Sardeson.
Streptorhynchus filitextum, Hall.
S. minnesotensis, N. H. Winchell.
Zygospira recurrirostris, Hall.
Z. aquila, Sardeson.
Bucania bidorsata, Hall.
Helicotoma planulata, Salter.
Maclurea bigsbyi, Hall.
Murchisonia gracilis, Hall.
M. milleri, Hall.
M. tricarinata, Hall.
Pleurotomaria subconica, Hall.
Raphistoma lenticulare, Emmons.
R. nasoni, Hall.
Subulites elongatus, Emmons.
Trochonema beloitense, Whitfield.
Cypricardites rectirostris, Hall.
C. niota, Hall.
Tellenomya nasuta, Hall.
Modiolopsis plana, Hall.

The *Stictoporella* Bed.—The Buff and Blue limestones described above constitute the true Trenton limestone in Minnesota. The 10 feet here described as the *Stictoporella* bed is, however, partly composed of limestone strata from two to sixteen inches thick. But they are crystalline, very firm and compact strata, often called marble in the west. They contain few fossils except at their surfaces, but alternate with richly fossiliferous strata of shale.

In the Saint Anthony area, particularly within the cities of Minneapolis and Saint Paul, the proportion of crystalline limestone to the shale is about one to two, with the former predominating at the bottom. The junction with the Blue bed is defined either by a granular seam or a carbonaceous band, or less frequently by a sudden transition to "marble." While the succession of strata is somewhat variable, it is broadly stated as follows: A stratum of purple crystalline stone 6 to 8 inches thick; a thin layer of shale; a gray crystalline stratum 18 to 24 inches thick; shale; bluish limestone 6 to 8 inches; and shale with thin strata of limestone and carbonaceous laminæ to the top of the series. In the southern area limestone layers predominate over the shale.

The name given to this series of layers is suggested by the abundance of remains of *Stictoporella*.*

*The names *Stictoporella* and *Stictopora* given to two of these Lower Silurian beds are from two genera of bryozoa abundant in them and at the same time somewhat restricted to them, as determined and described by E. O. Ulrich, Geol. and Nat. Hist. Sur. Minn., Ann. Rep. for 1885, pp. 66–72.

The fossils are:

Analoteichia impolita, Ulrich.
Pachydictya foliata, Ulrich.
Stictoporella frondifera, Ulrich.
Leptæna sericea, Sowerby.
Lingula elderi, Whitfield.
Orthis perveta, Conrad.
O. tricenaria, Conrad.
Rhynchonella ainsliei, N. H. Winchell.
R. minnesotensis, Sardeson.
Streptorhynchus filitextum, Hall.
Zygospira recurvirostris, Hall.
Helicotoma planulata, Salter.
Murchisonia gracilis, Hall.
Pleurotomaria subconica, Hall.
Raphistoma lenticulare, Emmons.
Productella minneapolis, Sardeson.

The *Stictopora* (or upper Blue) Bed.—This layer has a thickness of about 30 feet. It is made up of a dark-green rock, massive rather than shaly in its structure, and quite argillaceous in its composition. It carries a few crystalline slabs composed of firmly cemented fossils (figure 7). This bed weathers so rapidly as to give it the appearance of being very fossiliferous, but it is probably less so than the beds above. It affords a good illustration of effectual weathering when exerted on rock made up of such diverse elements.

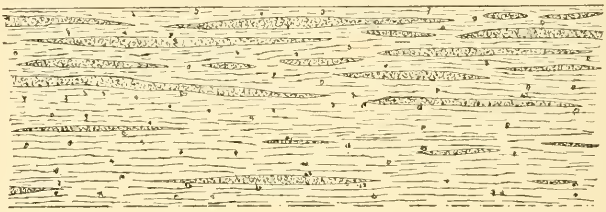


FIGURE 7.—*Lenticular Segregations of Fossils in the Stictopora Bed, Saint Paul.*

Lenses consist of closely packed and thoroughly cemented fossils within the mass of calcareous shale.

The fossils are:

Rhinidictya? *Raufella filosa*, Ulrich.
R. palmipes, Ulrich.
Pachydictya fimbriata, Ulrich.
Phylloporina reticulata, Hall.
Prasopora contigua, Ulrich.
Stictopora mutabilis, Ulrich.
Stictoporella cribrosa, Ulrich.
Crania halli, Sardeson.
C. setigera, Hall.
C. trentonensis, Hall.
Zygospira recurvirostris, Hall.
Bellerophon bilobatus, Sowerby.
Bucania bidorsata, Hall.
Conchopeltis obtusa, Sardeson.
Cyclonema semicarinatum, Salter.
Holopea symmetrica, Hall.
Murchisonia gracilis, Hall.
M. milleri, Hall.
M. tricarinata, Hall.
Pleurotomaria clivosa, Sardeson.

Leptæna sericea, Sowerby.
Orthis bellarugosa, Conrad.
O. subæquata, Conrad.
O. testudinaria, Dalman (variety).
O. tricenaria, Conrad.
Rhynchonella ainsliei, N. H. Winchell.
R. minnesotensis, Sardeson.
Streptorhynchus filitextum, Hall.
Strophomena alternata (?), Conrad.
S. halli, Sardeson.
S. inquassa, Sardeson.
P. subconica, Hall.
Raphistoma lenticulare, Emmons.
Subulites elongatus, Emmons.
Trochonema umbilicatum, Hall.
Cypricardites subtruncatus, Hall.
C. ventricosus, Hall.
Modiolopsis plana, Hall.
M. superba, Hall.
M. faba, Emmons.
Tellinomya levata, Hall.
T. ventricosa, Hall.
Whitella compressa, Ulrich.

The Fucoid Bed.—This is 20 feet thick, consisting chiefly of very argillaceous material so abounding in fucoidal remains that the name Fucoid is given. It differs from the underlying *Stictopora* bed in being full of calcareous and siliceous laminæ, besides masses of sponges, *Raufella filiosa* and *R. palmipes*, and various bryozoa. There are also thin layers of limestone from one to six inches thick, of which one is markedly oolitic and limonitic. In these respects this layer reminds one of the oolitic top of the upper magnesian layer, Shakopee *A*. This oolitic-limonitic layer has been recognized in Ramsey, Goodhue and Fillmore counties. The uppermost strata are of firm crystalline limestone, 3 feet in thickness at Saint Paul. It may prove to be less firm in the Southern area of the formation.

The fossils are as follows:

Phylloporina corticosa, Ulrich.
Prasopora contigua, Ulrich.
P. conoidea, Ulrich.
Pachydictya occidentalis, Ulrich.
Stictopora mutabilis, Ulrich.
Crania setigera, Hall.
Leptæna sericea, Sowerby.
Orthis minnesotensis, Sardeson.
O. pectinella, Emmons.
O. subæquata, Conrad.
O. rogata, Sardeson.
O. tricenaria, Conrad.
Rhynchonella increbescens, Hall.
Streptorhynchus filitextum, Hall.
Strophomena alternata, Conrad.
S. minnesotensis (?), N. H. Winchell.
Zygospira recurvirostris, Hall.
Murchisonia milleri, Hall.
Pleurotomaria subconica, Hall.
Subulites elongatus. Emmons.

The *Zygóspira* Bed.—A layer 8 feet thick from the top of the Fucoid bed upward has been separated mainly on paleontologic grounds; yet it may be distinguished from the Fucoid bed by the presence within it of numerous rounded calcareous masses rather than calcareous laminæ such as those of superior member.

The fauna is meager in species, yet remarkably abundant in individuals. It is as follows:

Pachydictya occidentalis, Ulrich.
Stictopora mutabilis (?), Ulrich.
Leptæna minnesotensis, Sardeson
Orthis minnesotensis, Sardeson.
O. pectinella, Emmons.
O. rogata, Sardeson.
O. tricenaria, Conrad.
Pholidops trentonensis (?), Hall.
Rhynchonella increbescens, Hall.
Streptorhynchus subsulcatum, Sardeson.
Strophomena alternata, Conrad.
Zygospira recurrirostris Hall.
Bellerophon bilobatus, Sowerby.
Modiolopsis rectiformis (?), Worthen.

The *Orthisina* Bed.—This bed is of varying thickness. It may be considered, perhaps, the first of the Galena beds. It is made up of shaly limestone, shales with calcareous lumps and firm but thin calcareous strata. Fossils are very numerous, both in individuals and species: mollusca are well preserved in the calcareous parts and molluscoidea in the shales. It is well exposed at Kenyon. The name is given from one of its characteristic species.

The fossils are—

Receptaculites iowensis, Owen.
R. oweni, Hall.
Pachydictya occidentalis, Ulrich.
Leptæna minnesotensis, Sardeson.
Lingula recinaformis (?), Hall.
Orthis biforata, Schlotheim.
O. minnesotensis, Sardeson.
O. rogata, Sardeson.
O. tricenaria, Conrad.
Orthisina americana, Whitfield.
Pholidops trentonensis (?), Hall.
Rhynchonella increbescens, Hall.
R. sancta, Sardeson.
Streptorhynchus filitextum, Hall.
S. subsulcatum, Sardeson.
Strophomena alternata, Conrad.
Zygospira recurrirostris, Hall.
Bellerophon bilobatus, Sowerby.
Bucania bidorsata, Hall.
B. buelli, Whitfield.
B. punctifrons, Emmons.
Fusispira elongata, Hall.
Holopea perundosa, Sardeson.
Murchisonia alexandra, Billings.
M. bellicincta, Hall.
M. gracilis, Hall.
M. milleri, Hall.
Raphistoma lenticulare, Emmons.
Subulites elongatus, Emmons.
Trochonema umbilicatum, Hall.
Tellenomya astartæformis, Salter.
Whitella truncata, Ulrich.

The *Camarella* Bed.—This member of the series is 30 feet thick. The bed is composed of carbonaceous limestone which quarries very well, yet splits into thin irregular laminæ when exposed to the air. It is quite impregnated with iron pyrites with some chalcopyrite intermingled. It is separated quite sharply from the *Orthisina* bed and differs from it in possessing few fossils, as well as in faunal and lithologic characters. Its fossils are—

Camarella bernensis, Sardeson.
C. hemiplicata, Hall.
C. owatonnensis, Sardeson.
Crania trentonensis (?), Hall.
Discina concordensis, Sardeson.
Leptæna minnesotensis, Sardeson.
Lingulella iowensis, Owen.
Orthis bellarugosa, Conrad.
O. biforata, Schlotheim.
O. rogata, Sardeson.
Streptorhynchus rhomboidalis, Wilckens.
Strophomena minnesotensis (?), N. H. Winchell.
Zygospira recurvirostris, Hall.
Bellerophon bilobatus, Sowerby.
Fusispira elongata, Hall.
F. ventricosa, Hall.

The *Lingulasma* Bed.—This division is 20 feet thick, consisting of very heavily bedded limestone and containing few fossils or impurities of any kind. In places it is strikingly colored by infiltration bands. From this appearance it is by quarrymen called a sandstone, although destitute of quartz grains. It is an excellent building stone. In fossils it carries—

Discina concordensis, Sardeson.
Lingulasma schucherti (?), Ulrich.
Lingulella iowensis, Owen.
Orthis bellarugosa, Conrad.
O. biforata, Schlotheim.
O. rogata, Sardeson.
Bucania punctifrons, Emmons.

The *Maclurea* Bed.—This is a coarsely bedded limestone. In weathering it passes into a coarse porous rock strongly resembling a sandstone in some respects; it develops a marked staining through the infiltration of ferric oxide along its joints. Perpendicular bluffs exposing all or nearly all of its thickness are quite common.

Its fossils are few but, for the Minnesota Silurian, of unusually large size. On account of their rarity they can be found only where large quantities of rather fresh débris are accumulated in quarries and the gorges of streams. These have been noted:

Receptaculites oweni, Hall.
Fusispira elongata, Hall.
F. ventricosa, Hall.
Maclurea cuneata, Whitf.
M. major, Hall.

THE CINCINNATI LIMESTONES AND SHALES.

The Maquoketa Beds: Localities.—These beds are displayed at Granger, three miles west of Forestville, and near Spring Valley; everywhere in small exposures.

Structural Characters.—This is a heavily bedded crystalline limestone alternating with beds of shale. The limestone predominates in the lower layers and the shales in the upper. The shales may easily be mistaken in lithologic and structural characters for the *Stictoporella* bed of the Trenton. The thickness of these rocks in the exposures visited is about

20 feet. The entire thickness is not known, since at no single exposure have both top and bottom layers been seen; but it is estimated at 30 or more feet. The limestone layers contain trilobite and *Endoceras* remains in good preservation. The shales contain the remains of a few species of molluscoidea in great numbers.

Lithologic Characters.—The crystalline condition of portions of these shales has just been mentioned. The typical hand specimens show a strikingly mottled stone, which displays varying shades of light brown, faint yellow and white (see plate 12, figure 6). In texture it is much finer than the average Lower Silurian limestones or somewhat massive shales. It is not thoroughly crystalline, but is made up of partially crystalline material, with immense numbers of minute fossils, apparently of many and diverse species.

Paleontologic Characters.—The following fossils have been identified:

Leptæna præcosis, Sardeson.
Orthis corpulenta, Sardeson.
Streptorhynchus trilobatum, Owen.
Strophomena alternata (?), Hall.
S. unicostata, M. and W.

The Wykoff Beds: Localities.—These beds are seen in Fillmore county, between Wykoff and Spring Valley, and at Spring Valley in exposures along the Chicago, Milwaukee and Saint Paul railway. In the town of Bristol, near Granger village, there are several small exposures.

Structural Characters.—The Cincinnati limestone of Minnesota under the above designation, one suggested by the prominent characters it displays near the village of Wykoff, in the western part of Fillmore county, is rather heavily bedded. It is only 20 to 25 feet thick along the railway named, but it becomes 70 feet or more in thickness only 15 miles further southward along the Iowa line, in Bristol. It is easily eroded, and a shaly appearance is the first and most conspicuous result of this action. In fact the term "shale," which has sometimes been applied to this series of strata, by no means expresses its lithologic or structural condition when fresh and unaltered material is seen.

Paleontologic Characters.—The following fossils are known:

Leptæna recedens, Sardeson.
L. saxea, Sardeson.
Orthis corpulenta, Sardeson.
O. kankakensis, McChesney.
O. macrior, Sardeson.
O. petræ, Sardeson.
O. subquadrata, Hall.
Rhynchonella capax, Conrad.
Streptorhynchus trilobatum, Owen.
S. wisconsensis, Whitfield.
Strophomena alternata (?), Hall.
S. unicostata, M. and W.
Bellerophon bilobatus, Sowerby.
Murchisonia gracilis, Hall.
Pterinea demissa, Hall.
Tellinomya lepida, Sardeson.
Modiolopsis modiolaris, Hall.

The lists of fossils from the Lower Silurian thus far given are intentionally limited mainly to certain abundant and representative classes. In addition to these a few species can be enumerated as belonging to all or nearly all of the Lower Silurian rocks:

Streptelasma corniculum, Hall.
Orthis testudinaria, Dalman (varieties).
Bellerophon bilobatus, Sowerby.
Murchisonia gracilis, Hall.
Murchisonia milleri, Hall.

The Devonian.

Localities.—Rocks of this age are found in Mower county at Austin and Leroy and eastward from Grand Meadow; and in Fillmore county at Spring Valley and in the southwestern corner in several exposures of a porous crumbling rock. This formation doubtless underlies all the territory between the points named.

Structural Characters.—In its lower layers the Devonian is a medium grained siliceous limestone. Near Austin it is gray in color. It has a very harsh feel. It stains readily when exposed, either at the surface or along its joints, to atmosphere and moisture, becoming dirty brown in color or, as at Spring Valley, of a yellowish tint. It is usually quite massive, breaking into irregular blocks when quarried. In some localities it is quite porous, due in part to the removal of some of its mineral matter and in part to the presence of large numbers of casts of some half dozen fossil species.*

Lithologic Characters.—A medium texture, a granular condition, and in places a crystalline or a semi-crystalline character prevails. So far as the specimens at hand have been examined, they lack the rhombohedral form of grain so predominant in the upper Cambrian and Lower Silurian. This fact is doubtless due to the compacter condition of these and the additional fact, to which the rocks everywhere bear evidence, that they are far less altered than are those of the two groups named.

Paleontology.—The fossils of the Minnesota Devonian are few and poorly preserved. Casts of *Atrypa reticularis*, Hall, *Spirifera pennata*, Hall, and other brachiopods not yet determined occur, together with several gasteropods. *Heliophyllum halli* and *Cyathophyllum* (sp.?) have been found in the drift of Mower county. Many bowlders of a Devonian coralline limestone are picked up around Austin, and they, if searched, would no doubt disclose several species.

*Some details not here mentioned can be found in the Geology of Minnesota, Final Report, vol. i, 1884, pp. 303, 357.

Summary of the Stratigraphy.

The following summary of thicknesses and leading lithological characters is given on the determinations of several authorities. The larger number are from measurements and determinations by the writers.

						Feet.
Devonian			Not subdivided	limestone and shale		10– 15
Lower Silurian.	Cincinnati		Wykoff	limestone	50	70
			Maquoketa	shale and limestone	20	
	Trenton	Galena	*Maclurea*	limestone	50	120
			Lingulasma	limestone	20	
			Camarella	shaly limestone	30	
			Orthisina	calcareous shale	20	
		Trenton	*Zygospira*	shale	8	95
			Fucoid	shale	20	
			Stictopora	shale	30	
			Stictoporella	limestone and shale	10	
			Blue	limestone	12	
			Buff	limestone	15	
	Saint Peter		Not subdivided	sandstone		75– 164
Upper Cambrian	Magnesian		Upper Shakopee	dolomite		10– 65
			Elevator *B* (Richmond)	sandstone		20
			Lower Shakopee	dolomite		75– 175
			Jordan	sandstone		75– 200
			Saint Lawrence	dolomites and shales		30– 213
	Potsdam		Not subdivided	sandstones and shales		0– 1,300
Total thickness of Paleozoic strata in Minnesota						560– 2,437

EXPLANATION OF PLATES 11 AND 12.

Plate 11.—Paleozoic Rocks of Minnesota.

Figure 1.—Basal conglomerate of the Potsdam at Taylors Falls; the bowlders are diabase from contiguous masses of that rock.

Figure 2.—Contact of Trenton limestone and Saint Peter sandstone at Minneapolis in the gorge of the Mississippi river between the Washington avenue bridge and the State university campus.

Plate 12.—Thin Sections of Minnesota Paleozoic Rocks.

Figure 1.—Dolomite, middle Magnesian, Hastings; rhombohedral character shown in a closely crystalline rock. × 70.

Figure 2.—Dolomite, Magnesian series, Mankato; rhombohedra with granular centers and transparent rims. × 70.

Figure 3.—Dolomite, Magnesian series, Frontenac old quarry; the arrangement of infiltrated coloring matter produces a pseudo-oolitic structure. × 34.

Figure 4.—Siliceous oolite, upper Shakopee (fragment found at Ottawa); centers of spheres show enlargement of rounded quartz grains, *i. e.*, crystal fragments with subsequent enlargement through deposition of microcrystalline silica. The lines show the direction of extinction.

Figure 5.—From a shaly band in the buff limestone, Minneapolis; under crossed nicols to show rhombohedral outlines of the grains.

Figure 6.—Maquoketa limestone, slightly magnified; showing mottling characteristic of the rock in typical Minnesota localities.

FIG. 1.—BASAL CONGLOMERATE OF THE POTSDAM.

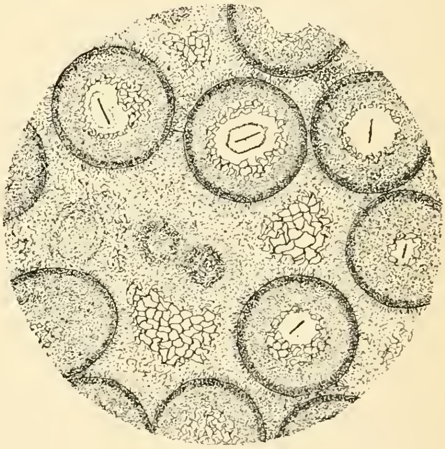
FIG. 2.—CONTACT OF THE TRENTON AND ST. PETER.

PALEOZOIC ROCKS OF MINNESOTA.

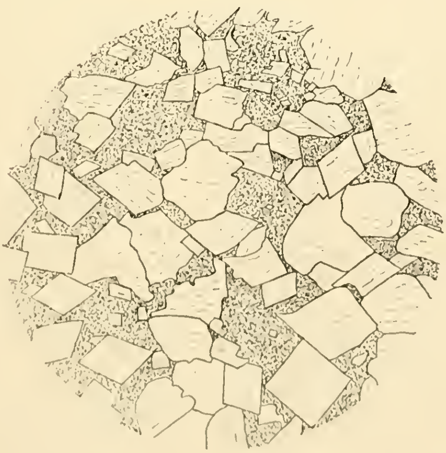
1.

2.

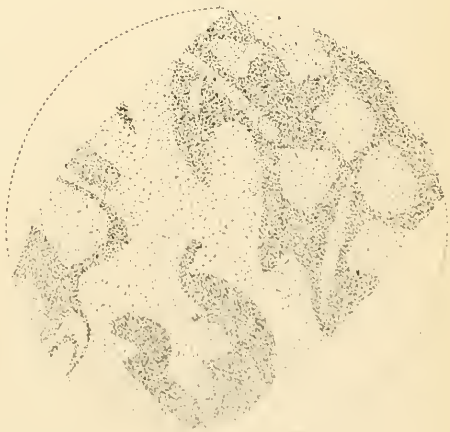
3.



4



5.



6.

Thin Sections of Minnesota Paleozoic Rocks.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
Vol. 3, pp. 369-394

GEOLOGY OF THE TAYLORVILLE REGION OF CALIFORNIA

BY

J. S. DILLER

OF THE UNITED STATES GEOLOGICAL SURVEY, WASHINGTON, D. C.

ROCHESTER
PUBLISHED BY THE SOCIETY
July, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 369-394 JULY 15, 1892

GEOLOGY OF THE TAYLORVILLE REGION OF CALIFORNIA.

BY J. S. DILLER, OF THE UNITED STATES GEOLOGICAL SURVEY, WASHINGTON, D. C.

(Read before the Society December 29, 1891.)

CONTENTS.

PART I—THE GEOLOGIC COLUMN.

INTRODUCTION.

Reconnoissance of the California Survey.—The Taylorville region of Plumas county, California, lies in the Sierra Nevada immediately north of the fortieth parallel. Reconnoitering parties of the California geological survey passed through the region in 1861 and 1863* and observed slates and sandstones, sometimes but little metamorphosed, also hard lava and granitic masses, and reported that "This part of the country is principally occupied by the metamorphic rocks over an area of about thirty miles in diameter." It is "Almost entirely surrounded by volcanic materials, the great lava streams which have come down from Lassen peak on the north and Pilot peak on the south uniting with the volcanic crest of the Sierra so as to cover the slates around three-quarters of the circumference of the circle." The state survey party in 1863 consisted of Messrs Brewer and King, who made two very important discoveries of fossils, the first near Mormon station, in the canyon about midway on the road from Indian to Genesee valley, where a considerable number of specimens of various genera and species were obtained. They were found principally on the spurs of rocks coming down from the north and in the canyons between them. According to Professor Whitney, the rock is a rather fine grained metamorphic sandstone, and portions of it are of a deep red color, resembling in appearance much of the Old Red or Devonian sandstone in England and on the continent. In places it is so much changed that the fossils have become nearly or even quite obliterated, but a number of species were obtained in a sufficiently good state of preservation to be determined. The specimens collected were referred to Mr. Meek for examination, and were considered by him to be almost certainly of Jurassic age.†

The second important locality of fossils discovered by Brewer and King in this region is on the northern side of Genesee valley, between the main belt of limestone and the granite. At this point there is a limited patch of calcareous slates containing quite a number of fossils. Some of them are very well preserved. Professor Whitney says these fossils belong to the Triassic series and prove clearly the existence at this point of the same formation which is so well developed in the Humboldt mining

*Geological Survey of California, vol. i, 1865, p. 307. The explorations were made by Mr. Ashburner in 1861 and by Messrs Brewer and King in 1863, under the direction of Professor Whitney, state geologist. The place called "Elizabethtown" in the above report is supposed to have been Taylorville, as it is on the way to Genesee valley, about eleven miles from Quincy, from which it is separated by a prominent mountain. Elizabethtown was much nearer Quincy.

† Ibid., p. 308.

region in Nevada, and also at Washoe, and which we have abundant evidence to prove extends over a vast area on the Pacific coast.*

Earlier Explorations of the United States Geological Survey.—The writer's first excursion through this region was made in 1885, and the results appeared in the United States Geological Survey Bulletin number 33 and in the 8th Annual Report of the Director of the United States Geological Survey, pages 401–432; but the detailed study of the region was not systematically undertaken until 1890.

In the meantime the region was visited on different occasions by Mr. I. C. Russell, Professor Hyatt, Mr. H. W. Turner, and Dr. Cooper Curtice. The extensive collections made in 1887 by Professor Hyatt and Mr. Russell, who spent several weeks in the region, were obtained chiefly from two horizons in the Jura and in the Trias; but since that time, in 1890 and 1891, Professor Hyatt has spent several months with me in the field and made still larger collections from all the horizons in the Jura and Trias, as well as from a number of older formations. Too great praise cannot be given him for the assistance his paleontologic studies in the field have rendered me in working out the structure of this complicated region. Dr. Curtice was in the region nearly three weeks in 1890, and discovered a number of new fossiliferous rocks. From his collections Mr. Walcott determined the presence of the Silurian and Carboniferous, while Professor Hyatt recognized a new horizon in the Jura and the paleobotanists identified certain slates as Mesozoic.

TOPOGRAPHY OF THE TAYLORVILLE REGION.

The Taylorville region, as referred to in this paper, embraces an area about 12 miles in length, from northeast to southwest, and 6 miles in width.

To the northeast the region is limited by Kettle rock and the divide at the head of Hosselkus creek; to the southwest by Grizzly mountain, Hough peak, and Arlington heights, extending to American valley and Spanish creek. Mount Jura, so named on account of the Jurassic age of the rocks it contains, lies near the center, directly between Taylorville and Genesee. Other important localities referred to are Foreman and Peters ravines, which join the northern arm of Indian valley from the east; Hinchman ravine, on the eastern slope of mount Jura, and Hornfels point, immediately north of Genesee valley, opposite the school-house.

FORMATIONS OF THE TAYLORVILLE REGION.

Sedimentary Formations.—The accompanying table gives a summary of the geologic components of the Taylorville region. Three of the great

* Ibid., p. 309. See also "Auriferous Gravels of the Sierra Nevada of California" (Memoirs Mus. Comp. Zool. at Harvard College, vol. vi) 1879, pp. 39 and 40.

groups are represented—the Cenozoic, Mesozoic and Paleozoic,—and of these there are members in the Pleistocene, Neocene, Jura-Trias, Carboniferous and Silurian systems, belonging in a number of cases to well defined series.

Of sedimentary formations there are within the region at least eighteen, embracing alluvium, glacial deposits, auriferous gravels, volcanic tuff, limestone, conglomerate, sandstone, quartzite and slates; six of these are probably Paleozoic, nine are Mesozoic, and three Cenozoic.

Geologic Column of the Taylorville Region.

Group.	System.	Series	Numbers	Sedimentary formations.	Thickness in feet.
Cenozoic	Pleistocene.......	....	1	Valley alluvium.	
"	"	....	2	Glacial moraines.	
"	Neocene...........	Miocene...............	3	Johnson gravel (auriferous)...........	
Mesozoic	Jura (upper)	Corallian	4	Hinchman tuff........................	500
"	" "	Callovian..	5	Bicknell sandstone..	500
"	" (middle) ...	Inf. Oolite..........	6	Mormon sandstone........................	500
"	" "	" "	7	Thompson limestone..	10–30
"	" (lower)....	Upper Lias (?).......	8	Hardgrave sandstone......................	450
"	Trias (upper)....	Rhætic (?)............	9	Foreman beds	1,600
" (?)...	" (?).....	....	10	Trail beds.........	2,900
"	" (upper)....	Lower Karnic......	11	Hosselkus limestone.......	140
"	" "	Upper Noric.........	12	Swearinger slates { *Halobia* bed, *Rhabdoceras* bed, *Monotis* bed } ...	200
Paleozoic	Carboniferous...	....	13	Robinson beds.	1,150
" (?)...	" (?)	....	14	Shoo Fly beds..............................	8,600
"	" (?)	....	15	Arlington beds...............	5,700
"	Silurian (?)........	....	16	Taylorville slates..........................	1,800
"	"	Niagara............ ...	17	Montgomery limestone....................	10–60
"	" (?).......	....	18	Grizzly quartzite	400
					24,530

The valley alluvium has been deposited by Indian creek and its tributaries and fills Indian and Genesee valleys.

Glacial moraines are found on the slopes of Grizzly mountain, especially beneath Tower rock, where they reach nearly to Little Grizzly creek. A short distance northeast of Kettle rock a moraine forms the embankment containing Taylor lake.

The Johnson gravels are auriferous and have been mined at the Taylor and Peale diggings and at the head of Mountain meadows, where they have an altitude ranging from 5,000 to 5,600 feet, and contain the remains of Miocene plants.* Mr. Turner † has traced these gravels south of the fortieth parallel, through the Cascade mine to the vicinity of Haskell peak, where they have an elevation of 7,000 feet. The southerly inclination of the pebbles, the northerly slope of the deposits, and

* Eighth Annual Report of the Director of the U. S. Geological Survey, part i, 1889, pp. 401-432.
† Bull. Phil. Soc. of Washington D. C., vol. xi, 1892, p. 406.

the distribution of pebbles containing Jurassic fossils afford strong evidence that the stream by which the gravels were laid down flowed from the vicinity of Haskell peak northwardly across Genesee valley and the northern arm of Indian valley to the Mountain meadows.

There are five formations well exposed on mount Jura. These are the Hinchman tuff, Bicknell sandstone, Mormon sandstone, Thompson limestone and Hardgrave sandstone. They all contain an abundance of fossils, which Professor Hyatt regards as undoubtedly Jurassic. The Hinchman tuff is a greenish or gray sandrock composed in many places of lapilli. The Bicknell sandstone is light gray or bluish gray and sometimes tufaceous above. Its areal relation to the Hinchman tuff has not been satisfactorily determined. They appear to grade into each other, and yet they can be separated both on stratigraphic and paleontologic grounds. The Hinchman tuff from both points of view is supposed to be the younger. Both formations are well exposed in Hinchman ravine. As may be seen in Professor Hyatt's paper,* they are certainly younger than the other three Jurassic formations and belong to the upper Jura.

The Mormon sandstone is a fine grained, compact, gray fossiliferous sandstone containing several small beds of conglomerate. It is best exposed on the spurs of mount Jura above Donnerwirth's, at an elevation of about 4,400 feet. According to Professor Hyatt its fauna belongs to the middle Jura.

The Thompson limestone is gray above and red and impure below. Near Thompson's it is burned for lime, but its best exposure is between Thompson's and the summit of mount Jura, at an elevation of about 4,700 feet. Its position everywhere appears to clearly indicate that it lies between the Mormon and Hardgrave sandstones. According to Professor Hyatt, its fossils tend to show that it may be younger than the Mormon sandstone.†

The Hardgrave sandstone is the red rock of Mormon canyon from which Brewer and King collected fossils in 1863. According to Professor Hyatt this is the oldest formation of the Jurassic system in the Taylorville region, and should be classed as upper Trias.

The Foreman beds are well exposed on the grade of the Lucky S mine road. They contain slates and sandstones, besides several beds of conglomerate. Near Foreman's Mr. Curtice, in 1890, collected from the slates a few plant remains. Mr. E. G. Paul has since added largely to

* This volume, pp. 395–412.

† It was once supposed that all the limestone among the metamorphic rocks of the Sierra Nevada was of Carboniferous age (U. S. Geol. Surv. Bull. no. 33, p. 21), but it is now known that Jurassic, Triassic and Silurian, as well as Carboniferous, limestones occur in that region.

the collection. Professor Fontaine, who studied the collection, reports that it contains *Equisetum münsteri*, *Podozamites* or *Pterophyllum*, and three small ferns, besides *Acustichides princeps* and *Lagenopteris* or *Cheiropteris*. According to this paleontologist, in whose report the plants are described in some detail, "They are clearly Mesozoic and most probably Rhætic in age."*

The Hosselkus limestone is well exposed where burned for lime and near the Cosmopolitan mine, on the divide between Genesee valley and Hosselkus creek. It contains numerous remains of the genus *Arcestes*, with a few other fossils, besides abundant pentagonal crinoid stems. Although there are some round crinoid stems present, the preponderance of pentagonal ones, in connection with *Arcestes*, furnishes a ready means of distinguishing this upper Triassic limestone from those of Jurassic, Silurian or Carboniferous age. It is one of the most important formations of the Taylorville region, and has been recognized elsewhere at numerous outcrops between Spanish ranch and Prattville and at many other points far to the northwestward, even beyond Pit river, in the Klamath mountains.†

The Swearinger slates are dark and calcareous, with a thin blue limestone and some siliceous layers. They occur just above Swearinger's house, on the northern side of Genesee valley, and include the *Monotis* bed, *Rhabdoceras* limestone and *Halobia* slates of Hyatt. They are all upper Triassic and rest directly and unconformably upon the Carboniferous.

The Trail beds, which lie farther northeastward, have not furnished a sufficient number of characteristic fossils to determine their age. On structural grounds, however, they also are regarded as Triassic, and probably newer than the Hosselkus limestone.

The Robinson beds contain slates, conglomerate, tuff and sandstone, of which the last two are the most important. The sandstone is a purplish rock of great variability. One-fourth of a mile south 50° west of Robinson's, in Genesee valley, it becomes for a short distance an arenaceous limestone. This calcareous portion was discovered by Curtice and has yielded an abundance of Carboniferous fossils. The material of which it is composed is chiefly volcanic, and close by the locality just mentioned it passes into a well marked tuff. The latter sometimes to the naked eye closely resembles the porphyritic eruptive with which it is

*Letter of December 8, 1891.

†The name *Klamath mountains* was first used by Powell (lecture before the National Geographic Society, February 17, 1888, not published) to designate the topographic province in northwestern California and southwestern Oregon in which the Sierra Nevada, Cascade and Coast ranges meet. It embraces the mountains locally known near the coast, between the 40th and 44th parallels, as Yallo Balley, Bully Choop, Pit River, Marble, Trinity, South Fork, Scott, Eddy, Salmon, Siskiyou, Rogue River, Umpqua and Calapooya mountains.

associated. In some cases it can be distinguished from the porphyritic eruptive only by the presence of fossils.

The following is a list of the forms identified by Mr. Walcott* from the calcareous and tufaceous portions of the Robinson beds at the above localities:

Campophyllum (?).
Favosites.
Archæocidaris.
Fenestella, 2 sp. undet.
Spirifera lineata.
Spirifera camerata.
Aviculopecten, 2 sp.
Myalina, of *subquadrata* type.
Pleurotomaria, sp. (?).
Streptorhynchus crenistria.
Productus semireticulatus.
Crinoids.
Productus punctatus (?).
Meekella, like *striato-costata*, Cox.
Rhynchonella, sp. undet.
Aviculopecten interlineatus.
Edmondia, sp. undet.

Microscopic markings of *Favosites* have been found common in the sandstone and can be used occasionally in identifying it when all other fossils fail.

Lithostrotion is an abundant and characteristic form in the Carboniferous limestone at a number of points northwest of the Taylorville region. The absence of this form among the Carboniferous fossils of Genesee valley led me to suspect that there are two fossiliferous horizons in the Carboniferous of northern California, of which the limestone containing *Lithostrotion* is the older and the Robinson beds of Genesee the younger. In answer to my question, Mr. Walcott replied that "Two horizons appear to be represented in the Carboniferous fauna. The lower is at the locality west of Bass ranch, near Pit river; also south of Longville, on crest of Mosquito and Yellow creeks. A somewhat higher zone is indicated by the collection from southwest of Robinson's, Genesee valley, and the Little Grizzly locality on the Cascade Gravel Mine road, in Plumas county. The collections do not clearly define the lower and upper Carboniferous zones of the Mississippi valley, but they suggest that they are present."

The Shoo Fly beds include a limestone which crops out on Clear creek, about two miles southeast of Shoo Fly bridge. It contains traces of crinoid stems, but they are not sufficient to determine positively whether the limestone is Paleozoic or Mesozoic. On structural grounds, it is probably either Triassic or Carboniferous, perhaps with a slight presumption in favor of the latter.

The Arlington beds, which form Hough peak and Arlington heights,

* Report rendered December 8, 1891.

are slates and sandstone with traces of conglomerate. None of these formations have yielded fossils. Some of them are but little altered. As they lie beneath the Shoo Fly beds at one end and are associated with Silurian slates at the other, they are regarded as probably belonging to the upper Paleozoic.

The Taylorville slates and the Grizzly quartzites adjoin the Montgomery limestone, which is well exposed along Montgomery creek and the crest of Grizzly mountain. In collections made at these two localities by Mr. Curtice, Mr. Paul and myself, Mr. Walcott * identified the following forms:

Crinoid stems.	*Heliolites.*
Stromatopora, sp. (?)	*Halysites catenulatus.*
Zaphrentis.	*Orthis*, of the type of *O. flabellum.*
Syringapora, like *S. serpens.*	*Ormoceras* (Siphuncles of)

According to Mr. Walcott these fossils are undoubtedly Silurian and "Represent the Niagara horizon of the Mississippi valley and Appalachian provinces."

Eruptive Rocks.—A large part of the Taylorville region is occupied by eruptives, of which there is a great variety, not only in chemical composition and degree of crystallization, but also in manner and time of eruption. There are at least seventeen distinct masses of various eruptives distributed with considerable regularity throughout the whole region.

On the northern side of Genesee valley the diorite has greatly altered the Triassic rocks along its contact. It has converted large masses of them into hornfels. Some of the quartz porphyries or porphyrites may be of early Paleozoic eruption. The porphyrite a short distance southwest of Robinson's certainly dates from the Carboniferous, and during the Trias there were great eruptions of basic lavas. Large masses in mount Jura were extruded at the close of the Jurassic, and since the middle Neocene volcanic activity has played an important rôle in the geology of that region.

It is evident from what has been said concerning the eruptives of the Taylorville region that igneous activity did not make its first appearance there suddenly in a later geologic period, as we are apt to suppose, but that, as in British Columbia, it began far back in the Paleozoic and continued with many interruptions almost to the present.†

* Report rendered December 8, 1891.

†See Geology of British Columbia, by George M. Dawson (Geol. Mag., dec. ii, vol. viii, April and May, 1881, p. 17); see also Later Phys. Geol. of the Rocky Mountain Region of Canada, with special reference to changes of elevation and the history of the Glacial Period (Trans. Roy. Soc. of Canada, vol. viii, sec. 4, 1890, p. 6) by the same author.

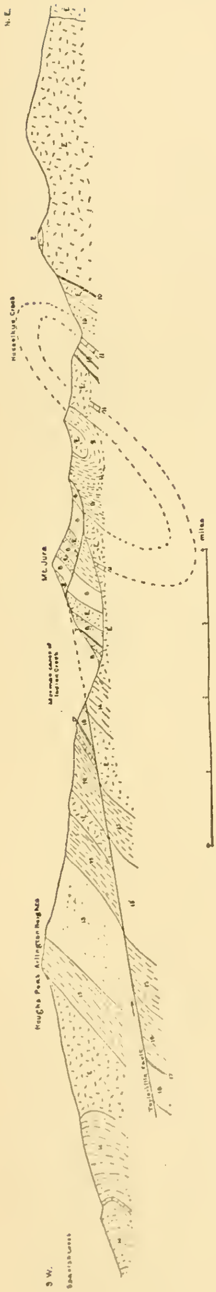


FIGURE 1.—*General Section through the Taylorville Region.*

1 = Hinchman tuff; 5 = Bicknell sandstone; 6 = Mormon sandstone; 7 = Thompson limestone; 8 = Hardgrave sandstone; 9 = Foreman beds; 10 = Trail beds; 11 = Hosselkus limestone; 13 = Robinson beds; 14 = Shoo Fly beds; 15 = Arlington beds; 16 = Taylorville slates; 17 = Montgomery limestone; 18 = Grizzly quartzite; *E* = Eruptive rocks.

PART II—STRUCTURE.

INTRODUCTION.

In the first part of this paper the geologic formations of the Taylorville region were briefly discussed, so far as their composition is concerned. It is now proposed to consider their geologic structure.

One section 17 miles in length, and four smaller parallel sections, varying in length from three-fourths of a mile to one and one-half miles, were carefully measured with a tape. The thicknesses of the formations determined by these measurements are given in the tabular view of the geologic column on page 372, and the structure is indicated in the accompanying figures.

The long section (figure 1) throughout its whole extent was measured almost continuously in the direction north 70° 30′ east. Beginning on the southwest at an elevation of 3,100 feet on Spanish creek, it crosses Hough peak at 7,254 feet, and reaches Indian creek, one and one-half miles above Taylorville, at an altitude of 3,500 feet. Continuing in the same course, it crosses mount Jura at 6,000 feet about one-third of a mile south of the summit. The upper portion of Hinchman ravine and other small ravines are crossed to reach Hosselkus creek, two and three-fourth miles above Genesee, at an elevation of 4,050 feet. From thence, at an elevation of 6,500 feet, it passes over the northern portion of Hornfels point, and skirts along the top of the southern slope of the mountain, whose summit is three miles directly north of Flournoy's.

The strike of the rocks throughout the region is north 5° to 65° west, and the dip.

with rare exceptions in the Shoo Fly and Foreman beds, is toward the southwest at angles varying from 39° to 75°.

It is evident that one of the first problems to solve in analyzing the Taylorville general section concerns the position of each formation in relation to those immediately above and below; or, in other words, to determine the original conformities and unconformities among the sedimentary rocks involved. This is a difficult task in the Taylorville region, where the stratified rocks are frequently penetrated and otherwise associated with eruptive masses, and all of them save the auriferous gravels and later formations have been involved in profound foldings and dislocations.

Among the rocks extending from well down in the Silurian to the late Pleistocene there are four breaks in the conformable superposition of the strata. These unconformities may be designated respectively by the horizons between which they occur, as the Neocene-Jura, Jura-Trias, Trias-Carboniferous and Pleistocene-Neocene.

Unconformities.

Trias-Carboniferous Unconformity.—The relation of the Trias to the Carboniferous is best exposed on the northern slope of Genesee valley opposite Robinson's, where the accompanying section (figure 2) was measured.

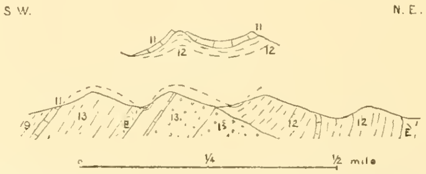


Figure 2.—*Section of Genesee Valley near Robinson's.*

9 = Foreman beds; 11 = Hosselkus limestone; 12 = Swearinger slates; 13 = Robinson beds; *E* = Eruptive rocks.

Beginning with the limestone on the left-hand spur where it has been burned for lime, we find it contains fossils that identify it with the Hosselkus limestone of the next two spurs to the eastward. This spur is made up chiefly of slates in which no fossils have been found. The first ravine toward the right is cut in the porphyrite, the eastern side of which is tufaceous and belongs to the Robinson beds. The tuff and calcareous sandstone both contain an abundance of Carboniferous fossils, and in connection with the tufaceous conglomerate which underlies the sandstone they form the second spur of the section up to an elevation of 4,500 feet. Above that point the spur is composed of *Halobia* slates and the Hosselkus limestone as represented in figure 2, and both of these

formations contain an abundance of Triassic fossils. They form an arch over the spur to both ravines, down which they extend far enough to appear in the lower section of figure 2. The strike of the Carboniferous strata on the lower part of the spur carries them directly and unconformably beneath the Triassic arch.

The Carboniferous and Trias are exposed near together for some distance along the Genesee anticlinal, but northwest of the divide between Genesee valley and Hosselkus creek they are so folded and eroded as to render their unconformity indistinct.

Mr. King has shown that there was probably an upheaval at the close of the Carboniferous, making a land area in eastern Nevada, and felt altogether assured in the belief that the Trias and Carboniferous were unconformable further westward.*

Professor Hyatt has shown that the Trias of Taylorville is upper Trias, later than that of the Aspen mountains, Idaho, or of the Star Peak range, Nevada. The Trias-Carboniferous unconformity, therefore, apparently represents a rather long time interval. The absence of the earlier Trias may be taken either as an indication that the northern Sierra region was a land area during that epoch or that the earlier Trias was eroded before the deposition of the later Trias. It is not impossible that the earlier Trias occurs yet undiscovered in the northern Sierra Nevada.

Dr. George M. Dawson reports that the Nicola Triassic rocks rest unconformably on the Carboniferous in the southern portion of the interior of the province of British Columbia.†

Jura-Trias Unconformity.—One and one-half miles southeast of Peters', in the southwestern branch of the ravine which heads near the Taylor diggings, at an altitude of nearly 5,000 feet, the Mormon sandstone (Jurassic) may be seen resting directly and unconformably upon the Hosselkus limestone (Triassic). Both formations contain their characteristic fossils, and Professor Hyatt, who visited this locality with me, agrees that there can be no doubt as to the identification of the rocks concerned. Their exposed areas are rather small, confined to the central portion of the ravine, and limited on all sides by eruptives. They have been traced along the ravine for about one-half mile, with a difference of nearly 1,000 feet in the altitudes of the terminal portions.

The angle between the strikes of the two formations is 62°, and their dips are at right angles to each other. In different portions of the area the strike varies considerably in direction, but it is evident near their contact that the trend of the limestone carries it unconformably beneath the sandstone. Their relations are indicated in the accompanying

* Geological Exploration of the Fortieth Parallel, vol. i, Systematic Geology, pp. 249-357.

† Geology of British Columbia; Geol. Magazine, decade ii, vol. viii, April and May, 1881, p. 17.

section (figure 3). These relations may be the result of either unconformable deposition or of displacement, or of both.

The sandstone near the contact is much fractured and the pieces in in many cases are bounded by slickensides. The fossils, which are well marked in some cases within a rod of the contact, gradually disappear in that direction as the slickensides increase. The Mormon sandstone is not the bottom member of the Jura but the third counting from below upward, the Hardgrave sandstone being lowest and the Thompson limestone next. The absence of the lower beds of the Jura and the presence of numerous slickensides near the plane of the contact render it probable that there is displacement at this point. Furthermore, a large mass of the Triassic slates and sandstones, which are younger than the Hosselkus limestone, do not appear between it and the Mormon sandstone; but this fact may find its explanation either in the displacement of the beds or in post-Triassic folding and erosion previous to the unconformable deposition of the Jura. The Mormon sandstone in Peters ravine lies at least in large part between the Carboniferous and the Trias, a feature which is forcibly repeated in mount Jura, and is fully described in a subsequent paragraph. Whatever may have been their relative position at this place originally, it is evident that great changes have been wrought in it during the folding of the rock at a later epoch.

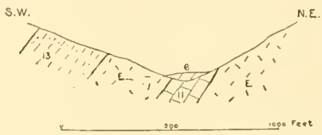


FIGURE 3.—*Jura-Trias Unconformity.*

6 = Mormon sandstone; 11 = Hosselkus limestone; 13 = Robinson beds; *E* = Eruptive rocks.

Strong evidence of an unconformity by deposition between the Jurassic strata and the older rocks is obtained by a general survey of their areal relations. In connection with the eruptives associated with them the Jurassic strata form the whole of mount Jura and, with a few exceptions, are limited to its slopes. The belt in which they occur is two and one-half miles in width, with a length parallel to the strike of about five miles. Although the Jurassic rocks, full of fossils, are well exposed along the southern side of the northern arm for one and one-half miles, with a strike to the northwestward, yet it has not been definitely proven that any of them appear on the other side of the valley, only a short distance away.

At the southern base of mount Jura the Jurassic rocks cross Indian creek to the slope of Grizzly mountain, but the exposures are small, embracing only detached masses of the Hardgrave sandstone, the Thomp-

son limestone, and the Mormon sandstone, completely surrounded by eruptive rocks. The thickness of the Jurassic rocks in mount Jura is 2,000 feet. The occurrence of so large a mass of rocks, the newest of the series well exposed for so short a distance, while the associated older rocks upon the sides extend beyond, tends to show that beneath the Jura there is an unconformity.

The strongest evidence, however, is found in the occurrence of a large exposure of the fossiliferous Hosselkus limestone at an elevation of 4,800 feet, on the slope of Grizzly mountain (figure 4), about two miles southwest of Genesee (Hosselkus'). The strike of the limestone at this point carries it directly beneath the middle portion of mount Jura, where it is completely covered up by the unconformably overlying Jurassic rocks.

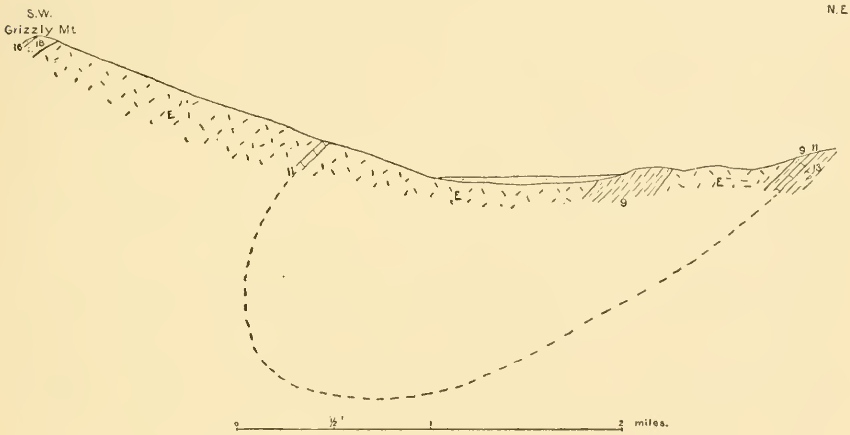


FIGURE 4.—*Section on northeastern slope of Grizzly Mountain.*

9 = Foreman beds; 11 = Hosselkus limestone; 13 = Robinson beds; 16 = Taylorville slates; 18 = Grizzly quartz; *E* = Eruptive rocks.

The sedimentary rocks lying immediately west of the Jurassic are the non-fossiliferous gray sandstone near Donnerwirth's, the Grizzly quartzite, and the Montgomery creek limestone. At least one of these is certainly Silurian, and all are Paleozoic. To the eastward the Jurassic beds are bounded by the Trias. The presence of rather heavy and coarse conglomerates in the Foreman beds, as well as delicate land plants in the same series, clearly indicates that the youngest Triassic beds of the Taylorville region were laid down not only in shallow seas but near land.

The dip of the strata, as shown in the long section (figure 1), from the Silurian at the summit of Grizzly on the one hand, across the Jurassic of mount Jura into the Triassic on the other, is uniformly southwestward. The Jurassic is thus folded in between the Paleozoic and the Trias,

a position given to it either by displacement or an original unconformity. Although the Jurassic system has been completely overturned and greatly displaced since its deposition, the character of the movements, so far as they have been made out, were not such as to explain its position folded between older strata of different ages, and we are constrained to believe that there is a marked unconformity at the base of the Jura caused by a folding of the strata at the close of the Triassic.

A general consideration of the character and distribution of Jurassic strata and fossils throws some light upon the ancient geography of the region. Professor Hyatt has shown that in the Jurassic rocks of Taylorville the three great subdivisions, namely, lower, middle and upper Jurassic, are represented, and that it contains a larger number of fragments of the series of the Jurassic system than any other known locality in the United States. Fragments of the Jurassic system have been recognized in Montana, Wyoming and the Great basin, as well as in California. The general scarcity, if not the complete absence, of vertebrate fossils in the Jurassic rocks of Taylorville indicates, according to Professor Hyatt, that the faunas lived at some distance from the shores of the Jurassic continent and in a more exposed oceanic area than those of the Great basin. He announces the fact also that the remains of Oolitic ammonites have been occasionally picked up west of the crest of the Sierra Nevada. It seems evident, therefore, that during a large part, if not the whole, of the Jurassic period the northern Sierra region was beneath the sea, and that the disturbance at the close of the Trias, although it folded and faulted the rocks, did not produce permanent dry land. The predominance of sandstones with occasional interbedded conglomerates, however, evidence rather shallow Jurassic seas at Taylorville.

According to Dr. Dawson, the disturbance at the close of the Triassic in British Columbia produced quite different results. He remarks:* "Though much remains to be discovered respecting this post-Triassic epoch of disturbance, it was evidently an important one, and its results were wide-spread in the Cordilleran region. It is quite possible that it was accompanied by or resulted in producing a general elevation of this entire region above the sea level, as no rocks certainly referable to the Jurassic or next succeeding period have yet been distinctly recognized either in British Columbia or in its bordering regions."

Neocene-Jura Unconformity.—The Johnson gravel is of fluviatile origin. Northeast of mount Jura it reposes unconformably upon the upturned edges of the massive Jurassic and Triassic formations. This unconformity is one of the most conspicuous of the region. It represents a

* Trans. Roy. Soc. of Canada, vol. viii, sec. iv, 1890, p. 7. See also paper by G. F. Becker, Bull. Geol. Soc. Am., vol. 2, 1890, p. 206.

great lapse of time, the records of which are to be found to the westward in the deposits bordering chiefly upon the Sacramento valley.

That there was in the northern Sierra Nevada region an epoch of great disturbance after the deposition of the Jurassic rocks near Taylorville is clearly shown by the fact that those rocks are overturned and faulted.* That the disturbance and elevation occurred immediately at the close of the Jura is rendered highly probable by the complete absence from the Taylorville section of any Cretaceous deposits. It is possible that the Cretaceous, if formerly present in that region, has been completely removed by the great erosion to which the Sierra Nevada has been long exposed; but of this view I have not been able to obtain any supporting evidence.

So far as yet known, on the fortieth parallel the rocks next younger than the Taylorville Jurassic are the Knoxville beds of the earlier Cretaceous. They are widely separated in space, and it is probable that there was between their periods of deposition a considerable lapse of time, within which the rocks of the Sierras were greatly deformed by compression and raised above the sea; consequently the shore-line of the Cretaceous sea scarcely reached the western base of the Sierra Nevada and laid down its deposits unconformably upon the older rocks.†

In order fully to comprehend what is represented by the Neocene-Jura unconformity of the Taylorville region it is necessary to consider the relation of the Johnson gravel to the Cretaceous rocks of the Sacramento valley. These gravels were deposited by a stream flowing into the Mountain meadows region, where some Miocene plant remains have been found. It has been shown ‡ that these sandstone and gravel strata probably connect beneath the lavas of Lassen peak with deposits of the same age on Little Cow creek, at the northeast corner of the Sacramento valley. At this last locality the Miocene strata rest unconformably on the Chico beds of the Cretaceous.

In the Neocene-Jura unconformity, therefore, we have represented not only the great time interval between the close of the Jura and the Miocene, but also two unconformities, the first, and by far the most conspicuous, between the Cretaceous and the Jura and the second between the Cretaceous and the Miocene.

Pleistocene-Neocene Unconformity.—The valley alluvium (Pleistocene) does not come in contact with the Johnson gravel, and yet their unconformity, due to erosion, is well marked. The valley alluvium was de-

* Bull. Geol. Soc. Am., vol, 2. p. 206.

† That the rocks of the Shasta group at Horsetown rest unconformably upon the older rocks is well known. Our knowledge of this unconformity has recently been much extended by Mr. H. W. Fairbanks in the American Geologist for March, 1892 (vol. ix, pp. 153-166).

‡ Eighth Ann. Rept. U. S. Geol. Survey, pt. i, pp. 119-122.

posited by Indian creek and its tributaries in canyons and valleys cut to the depth of 2,000 feet directly across the bed of the ancient stream by which the Johnson gravel was deposited. The character of the fossil plants found in the auriferous gravels at Mountain meadows and elsewhere in the same district, as well as the topography of the region, indicates that the northern end of the Sierra Nevada at the time the Johnson gravel was deposited had a much gentler relief and lower altitude than at the present time. As already shown,* the region was greatly affected by a post-Miocene upheaval.

DEFORMATION.

Structure of Mount Jura.—Having considered the four unconformities or structural breaks which occur in the suite of rocks of the Taylorville region, attention may be turned to the structure displayed by the youngest system, *i. e.*, the Jurassic. We may expect this system to be affected by the same kind of movements and other changes which took place in the older strata but, on account of its youth, to have been affected in a less degree, and therefore in certain respects to furnish better examples for study.

The strike of the rocks in mount Jura, with comparatively moderate variation, is northwest and southeast, while the dip is uniformly southwestward. On the western slope of the mountain the continuity of the stratified rocks is greatly interrupted by eruptive masses, but the stratigraphic order of the rocks is clearly defined. Near the base, next to the siliceous eruptive, occurs the Hardgrave sandstone, followed up the slope by porphyrite and the Thompson limestone, which dips beneath the Hardgrave sandstone and overlies the Mormon sandstone. Continuing up the slope, as shown in the section of mount Jura, we next come to a zone of porphyrite on which there are a number of small areas of stratified rocks, especially of the Hardgrave sandstone. This is succeeded, near the summit of the spur where the section crosses, by an acid eruptive and the Hardgrave sandstone, which are followed in order down the eastern slope toward Hinchman ravine by the Thompson limestone, Mormon sandstone, Bicknell sandstone and Hinchman tuff. This suite composes the smaller section down the western slope of Hinchman ravine, figure 5; but on the north the Thompson limestone and a portion of the Mormon sandstone are replaced by an eruptive. The order of the stratification on the western and eastern slopes of mount Jura is the same. In both cases the oldest stratum is on top and the youngest at the bottom of the suite, and it is evident that the whole mass has been overturned.

* U. S. Geol. Surv., Eighth Ann. Rept., 1886'87, pp. 419-422.

Furthermore, as shown in the foregoing section (figure 5) which crosses mount Jura approximately perpendicular to the strike, the Hard-

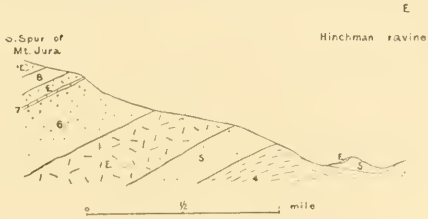


Figure 5.—*Eastern Slope of Mount Jura.*

4 = Hinchman tuff; 5 = Bicknell sandstone; 6 = Mormon sandstone; 7 = Thompson limestone; 8 = Hardgrave sandstone; *E* = Eruptive rocks.

grave sandstone, Thompson limestone and Mormon sandstone are repeated in exactly the same order on opposite slopes, as represented in figure 6. Such a repetition of the strata can be produced only by faulting.

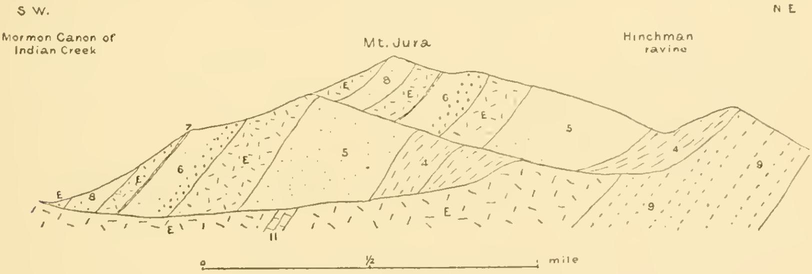


Figure 6.—*Section through Mount Jura.*

4 = Hinchman tuff; 5 = Bicknell sandstone; 6 = Mormon sandstone; 7 = Thompson limestone; 8 = Hardgrave sandstone; 9 = Foreman beds; 11 = Hosselkus limestone; *E* = Eruptive rocks.

We should expect the fault or its attendant phenomena to be displayed on the western slope of mount Jura, where the repetition begins, and in fact we find at that point a number of exposures deserving special mention.

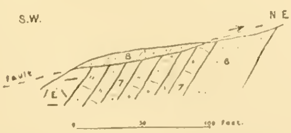


Figure 7.—*Section near Indian Village.*

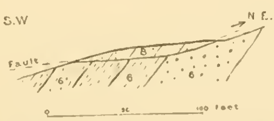


Figure 8.—*Section near Donnerwirth's*

6 = Mormon sandstone; 7 = Thompson limestone; 8 = Hardgrave sandstone; *E* = Eruptive rocks.

On the second prominent spur, which reaches the stage road south of the Indian village at an elevation of 5,100 feet, an outcrop nearly 100 feet in length is exposed. It is illustrated in figure 7.

A rather coarse gray sandstone, with a gentle southwesterly dip, is found lying unconformably upon more highly inclined red calcareous beds, which contain a number of small lenticular masses of gray limestone. No fossils were found in this locality in the red beds, but they are between the porphyrite and the Mormon sandstone, which is full of fossils; and the red beds themselves on the next spur to the southward contain *Opis* and an abundance of the screw-shaped gasteropods which characterize the Thompson limestone. In the overlying sandstone an ammonite was found, and from the lithologic character of the rock it is believed to belong to the upper portion of the Hardgrave sandstone. Whatever its geologic horizon, its present position is due to displacement from the southwestward, where the Hardgrave sandstone is exposed.

On the prominent spur which reaches the stage road in the bend by the narrows, one-third of a mile south of Donnerwirth's, at an elevation of 4,550 feet, a small mass of Hardgrave sandstone, with its characteristic fossils, occurs directly upon the Mormon sandstone, equally well defined by its fossils. The conglomerate near by is the one belonging to the middle portion of the Mormon sandstone. Figure 8 is a section of the exposure, and it is evident that the Hardgrave sandstone has been shoved into its present position from a short distance southwestward, where it is well displayed near the base of the mountain.

At a number of points on the western slope of mount Jura, a little above the elevation of 4,500 feet, small masses of Hardgrave sandstone occur, but as they are enveloped by porphyrite it is not so apparent that they have been faulted into their present position. A short distance further up the slope there is evidence of the faulting found in the breccia which underlies the siliceous eruptive. The breccia occurs at a number of points along the course of the fault. It is composed largely of the fragments of the superior rock and may be an eruptive, but a more plausible explanation attributes its origin to faulting.

The two outcrops noted in figures 7 and 8 are in the line of the general displacement, which causes a repetition of the oldest three Jurassic formations in mount Jura, and it is desirable to note that the amount of displacement in the two cases is different. While in the first case the Hardgrave sandstone is carried over upon the Thompson limestone, in the second it is carried beyond the Thompson limestone to near the middle of the Mormon sandstone, indicating that the amount of displacement in mount Jura is greatest in its southern portion. The same feature is more forcibly illustrated by the relation of the two masses, each of which is made up of the three repeated formations in mount Jura. While on the southern slope of the mountain these are separated by a throw of at least three-fourths of a mile, on the northern portion the displacement

is expressed chiefly in the widening of the exposure of the Mormon sandstone.

The evidences of faulting observed in the different parts of mount Jura are not to be considered as indicating so many faults, but rather different portions of one great fault.* If we join together all the surfaces along which faulting has taken place to form one continuous surface, it is evident that such a surface must be greatly warped. Its position on the western slope of mount Jura is quite clearly indicated by the exposures already noted. It first appears at an altitude of 5,100 feet in the one case, and 4,550 feet in the other. At both places the fault has a gentler dip southwestward than the slope on which it occurs, so that the fault surface at the points indicated leaves mount Jura in the direction of the lower slope of mount Grizzly. Above these points the fault surface is nearly parallel with the slope, but just below the siliceous eruptive it plunges deep into mount Jura with an easterly dip, along which the three formations of the western slope of the mountain are repeated in the same order on the opposite side.

It has been remarked that the throw of the fault in the northern portion of mount Jura is small, but in the southern portion of the mountain it is about three-fourths of a mile. The southeastern portion of the mountain, which is made up of the whole Jurassic series, has been shoved far to the eastward, so that the Hinchman tuff laps much further over upon the Foreman slates in that vicinity than further northward. Their easterly extension connects directly with the faulting, and we may consider that the fault, after passing through mount Jura with an easterly dip, rises to the surface again with westerly inclination between the Hinchman tuff and the Foreman slates, as shown in the section.

The fault on which the upper and eastern portion of mount Jura has been displaced is thus shown to be an irregularly curved or undulating surface, the general position of which is nearly horizontal, with a low inclination to the southwestward, and the average hade of the fault is toward the upthrow. It is evident also that the overturning of the Jurassic strata has been from the southwest toward the northeast, and that the faulting, which is in the same direction, has taken place subsequently but probably in immediate connection with the folding.

General Structure.—Consideration of the unconformities of the Taylorville section and of the structure of mount Jura prepares the way for a closer analysis of the structure of the whole region.

As already stated, the strike of the strata is approximately northwest

*The curvature of the fault surface is indeed considerable, but in this it does not differ from the major faults of the Scottish Highlands. In mount Jura the relation of the several parts does not appear to be that of major and minor faults, but rather different portions of the same narrow zone of displacement.

and southeast, so that the formations of the different geologic horizons appear in belts crossing the region in that direction. The long section represented in figure 1 crosses these belts approximately at right angles, and shows not only the positions of the strata observed, but also, in some cases, their connection beneath the surface.

It is evident that the strata have been either folded or faulted, or both, to bring them into their present position, and it is important to determine at the outset, if possible, the influence of each in developing the general structure.

A glance at the section of the region shows us that there are two belts of older strata—one in Grizzly mountain and the other in the vicinity of Hosselkus creek. These are both flanked on either side and separated by belts of younger strata: but all the strata, both older and younger, with rare exceptions, dip southwestward. This distribution might arise from either folding or faulting. It so happens, however, that in the northeastern belt of older strata the anticlinal structure is evident, and in the middle area of newer ones the synclinal arrangement is clearly indicated. There is good reason, therefore, for regarding the two masses of older formations as brought to the surface by anticlinal folds rather than by faults; but, as already seen in mount Jura, the folding and overturning of the strata may have been followed by displacement.

Genesee Anticlinal.—The Genesee anticlinal is best exposed on the northern slope of Genesee valley, where the Trias is arched unconformably over the Carboniferous, as represented in figure 2 (page 378).

Near the crest of the divide between Hosselkus creek and Genesee valley, not far from Robinson's, where the Hosselkus limestone passes over to the eastern side of the anticlinal, it disappears on the western side, its place being taken by a belt of eruptive rocks which borders the anticlinal immediately upon the west throughout its whole extent. On the eastern side, however, close to the axis, the Hosselkus limestone is well exposed along Hosselkus creek, ascending its western branch to near the Taylor diggings, where it is intercepted by eruptive rocks but reappears, as already stated, in the southwestern branch of Peters ravine, associated with Carboniferous and Jurassic strata.

The eastern arm of the anticlinal is very irregularly limited by eruptives. Near Genesee valley it is cut off by the diorite, leaving only a narrow belt of the Triassic slates, which are turned up near the contact and converted into hornfels. Further northward it suddenly expands, near Hornfels point, into a broad wedge-shaped area of the Trail beds, which are supposed to be Triassic. The area tapers rapidly northwestward under the encroachment of the eruptives from Kettle Rock mountain, which completely cut off the Genesee anticlinal on the southern slope of Peters ravine.

Northern Arm Synclinal.—Southwest of the Genesee anticlinal there is a broad synclinal of younger formations, extending from the Mormon canyon of Indian creek to nearly three miles northeast of mount Jura. The best exposures of the strata it contains, besides those of mount Jura, are to be found in the eastern branches of the northern arm, especially in the various gulches of Foreman ravine.

The detailed arrangement of the strata within the synclinal is not easily discerned. This is due chiefly to two causes: (1) the presence of a large mass of overturned Jurassic strata, which not only fails clearly to partake of the synclinal structure but appears by its unconformity to cover up other strata the repetition of which might be recognized; and (2) excepting the Jurassic strata, the formations exposed within the synclinal are poor in fossils, so that their correlation is a matter of considerable difficulty.

The central sandstone of the Foreman beds is well exposed in Foreman ravine, and bounded on both sides by slates which contain occasionally masses of conglomerate composed chiefly of quartz pebbles. The similarity in the general character of the two bodies of slates adjoining the central sandstone on opposite sides, taken in connection with the recurrence at corresponding positions within them of rather peculiar conglomerates, tends strongly to indicate that they are the same formation with synclinal connection beneath the central sandstone, but within the Foreman beds. In the section (figure 1) the place of the central sandstone in the middle of the synclinal is occupied by an eruptive. Although the Foreman beds appear to have been overturned and the synclinal closed, so that for the most part the dip is southwestward, there is a large portion of them near the northern end of mount Jura that dip northeastward, and it is possible that a part of the original open synclinal yet remains in that protected locality. A few fossil plants have been found in a slaty portion of the Foreman beds. They are regarded by Professor Fontaine as certainly Mesozoic and most probably Rhætic in age. A favorable opportunity has not yet occurred to search for them in all portions of the slates.

The Hosselkus limestone on the northeastern side of the synclinal is covered up through a large portion of its extent by the eruptives adjoining the Foreman beds. It is, however, well exposed in this position at the old lime-kiln on the northern slope of Genesee valley.

It has been recognized in the southwestern arm of the synclinal, at an elevation of 4,800 feet on the slope of Grizzly mountain (see figure 4), about two miles southwest of Hosselkus, where it is evident that a short distance further northward it must be concealed from view beneath the Jura.

Grizzly Anticlinal.—The existence of the Grizzly anticlinal is not so clearly defined as that of the Genesee, for its determination depends upon the presence of one fossiliferous stratum, viz. the Montgomery limestone (Silurian). The strata immediately adjoining this limestone on both sides are in general much more ancient looking than those coming next in order, and if we proceed far enough across the strike in either direction from the Silurian the first fossiliferous strata met with on both sides are much younger. Toward the northeast we need to proceed only a short distance, for the Jura, as shown in figures 1 and 9, appears at the very foot of mount Grizzly; but in the opposite direction the distance is much greater. Although the limestone of the Shoo Fly beds contains a few crinoids, no determinable fossiliferous strata are met with in that direction before reaching the Hosselkus limestone (Triassic) near the mouth of Rush creek.

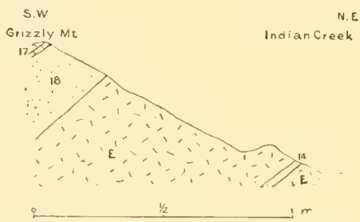


FIGURE 9.—*Northeastern Slope of Grizzly Mountain.*

8 = Hardgrave sandstone; 14 = Shoo Fly beds (?); 17 = Montgomery limestone; 18 = Grizzly quartzite; *E* = Eruptive rocks.

The distance from the Silurian to the Hosselkus limestone on the eastern side of the arch is about two miles, for, as we have shown, it lies unconformably beneath the middle portion of mount Jura, but in the opposite direction the distance is at least eight times as great.

While in the Genesee anticlinal the middle of the arch is clearly defined by the Carboniferous, which is flanked on both sides by the Triassic, in the Grizzly arch the middle formation is less evident. The oldest stratum known positively by its fossils is the Montgomery limestone, which appears in the very crest of Grizzly mountain (figure 9). It dips southwestward, overlying the Grizzly quartzite, and is itself overlain by the Taylorville slates. As the Grizzly quartzite is not the equivalent of the Taylorville slates, it is evident that the Montgomery limestone is not the middle formation of the anticlinal. A careful scrutiny of the folded strata on the measured section does not disclose any repetition which would locate the middle of the arch.

The crest of a mountain developed by erosion of an overturned anticlinal is generally formed of hard strata within the upper or long limb

of the arch, the middle or lowest stratum of the arch being exposed on the steeper slope in the direction of the overturning. From this point of view the oldest formation in the Grizzly anticlinal is apparently the Grizzly quartzite.

The older strata in the crest of the Grizzly anticlinal are depressed to the northward. In the summit of Grizzly mountain just north of the 40th parallel they have an elevation of 7,700 feet. From this point they gradually sink 4,200 feet in three and a half miles to the bridge across Indian creek, one-fourth of a mile east of Taylorville, where they pass beneath Indian valley at an elevation of 3,500 feet.

The western limb of the anticlinal embraces all of the formations lying between the northern extension of the crest of Grizzly mountain and Spanish creek. Beginning with the oldest, lying near the middle of the arch, they occur in the following order: Grizzly quartzite, Montgomery limestone, Taylorville slates, Arlington beds and Shoo Fly beds, together having a total thickness of over 16,000 feet.

The eastern limb of the Grizzly anticlinal was much contracted and obscured by the overturning, and none of the formations occurring in the western arm save the Hosselkus limestone, which is beyond the section, have been recognized on its eastern side. The obscurity is greatly increased by the presence of the Jura, which reposes on the older strata unconformably and covers them up. It seems most probable also, as will be shown in the sequel, that the case is still further complicated by faulting such as affected mount Jura.

Taylorville Fault.—The terminal portions of the long section are comparatively simple. Its greatest complexity lies near the middle, in the vicinity of the western base of mount Jura. As seen in considering the northeastern arm of the Grizzly anticlinal and the southwestern arm of the adjoining synclinal, this limb, which is an element of both, must be regarded as involving all the strata of the Taylorville region from the Silurian to the Jurassic, inclusive, having a total thickness of 24,500 feet. In considering this, however, we should reduce the total amount by 2,000 feet, the thickness of the Jurassic, which lies upon the older rocks unconformably, which would leave 22,500 feet for the section from the Silurian to the Triassic, inclusive. The actual thickness of the rocks, measured from the Grizzly anticlinal to the middle of the northern arm synclinal, is only about 9,000 feet, so that 13,500 feet of strata have suddenly disappeared from the middle portion of the section.

The structure of mount Jura at once suggests that the disappearance of this large body of strata may be due to a profound fault along the northeastern slope of Grizzly mountain. The fault which we have found distinctly marked in mount Jura leaves its southwestern slope for mount

Grizzly on the opposite side of Indian creek, just where we would expect the fault to occur. Furthermore, the Jura fault has produced exactly the same kind of effects, different only in degree from those we seek to explain.

The fault surface and some of the strata beneath have been exposed by erosion on the southwestern slope of mount Jura, but the immediate result of this faulting was to narrow the belt of Triassic exposures and cover them up to the northeastward of mount Jura by shoving over upon them the Jurassic formations from the southwestward.

The completely brecciated quartz-porphyry or quartz-porphyrite which occurs so abundantly on the northeastern slope of mount Grizzly overlying the fault was, in many cases at least, brecciated at the time of its eruption, but in other cases it more closely resembles a fault breccia and its genesis may then properly be attributed to the displacement.

The position of the fault on the lower slope of Grizzly has not been definitely traced out, as it has on the southwestern slope of mount Jura. It gradually sinks to the northward with the crest of Grizzly, reaching Indian creek some distance above the bridge. Continuing in the same direction, near Chapman's it cuts off a small portion of the northwestern corner of mount Jura; thence it crosses the northern arm and follows the eastern slope of the curved ridge between Cook canyon and Indian valley toward Mountain meadows.

On the western side of the northern arm the quartz-porphyry so abundant on the slopes of mount Grizzly is shoved far over to the northeastward upon the Foreman beds, so that the Jurassic formations, if they extend northwestward beyond the northern arm, are chiefly or wholly covered up by the fault. To the southward along the slope of Grizzly the position of the fault has not been definitely traced.

From the relative positions of the Hosselkus limestone, as seen in the long section and further to the westward, we can get some idea of the amount of displacement in the Taylorville fault. This limestone crops out about one and one-half miles northeast of the axis of the northern arm synclinal, so that its position in the other arm of the synclinal would be underneath the middle portion of mount Jura. The strike of this limestone, at its outcrop on the slope of mount Grizzly southwest of Genesee, carries it beneath mount Jura near the middle. If, now, the Shoo Fly limestone is Triassic (Hosselkus), as there is some reason for supposing, the thickness of the strata between the Hosselkus limestone and the Silurian on the southwestern side of the Grizzly arch is about 15,700 feet, and the Silurian should be expected below the fault nearly five miles southwest of the Hosselkus limestone underlying the middle of mount Jura. This would make the displacement of the Silurian

limestone about four miles. If the Shoo Fly limestone is Carboniferous the displacement must be greater. As this determination is based on estimated distances and uniformity of dip, it can only be considered a mere approximation. However, in magnitude it is not extraordinary as compared with the displacement of similar overthrust faults in the northwestern highlands of Scotland,* the Rocky mountains of Canada† and the southern Appalachians.‡

The Taylorville fault, as we have traced it across the northern arm, is found to have an irregularly undulating surface, with a very low general inclination southwestward, and is in fact part of the same fault which affects mount Jura. When we compare the total displacement along the Taylorville overthrust (about 4 miles) with the maximum faulting experienced by the overturned strata of mount Jura (three-fourths of a mile) we find the former exceeds the latter over three miles. This difference is large and suggestive. While it is possible that the supposed displacement of the Taylorville fault is too great, yet it is quite improbable that it is so small as one mile. The Taylorville fault may have had its inception in the folding that took place at the close of the Triassic, so that a large part of its displacement may be pre-Jurassic.

The Taylorville fault was formerly regarded as a normal fault,§ but later observations strongly indicate that it is an overthrust. Evidence has not been found to show positively that there has been any considerable amount of motion along the Taylorville fault within the later geologic epochs. The Tertiary stream which deposited the Johnson gravels appears to cross the fault immediately south of the fortieth parallel, and at that point, according to Mr. Turner,|| the "amount of faulting has been comparatively slight."

Summary.

There are in the Taylorville region 18 sedimentary formations and 17 eruptive masses. The former have a total thickness of 24,500 feet; 17,500 feet are probably Paleozoic, and 7,000 feet are Mesozoic.

Among the sedimentary rocks, one horizon in the Silurian, two in the Carboniferous, three or more in the Trias and five in the Jura have been definitely recognized by fossils.

* "The Crystalline Rocks of the Scottish Highlands:" A. Geikie, Nature, vol. xxxi, 1881, p. 29; also "Report on the Recent Work of the Geologic Survey in the Northwest Highlands of Scotland:" A. Geikie, Quart. Jour. Geol. Soc., vol. xliv, 1888, p. 378.

† "Report on the Geologic Structure of a Portion of the Rocky Mountains;" R. G. McConnell, Geol. Survey Canada, Annual Report for 1886, part D.

‡ The Overthrust Faults of the Southern Appalachians; C. Willard Hayes, Bull. Geol. Soc. Am., vol. 2, pp. 141–154, pls. 2 and 3.

§ U. S. Geol. Survey Bulletin no. 33, p. 13; also Eighth Ann. Rept. U. S. Geol. Survey, p. 426.

|| H. W. Turner; Mohawk Lake Beds: Bull. Phil. Soc. of Washington, vol. xi, p. 406.

Among the eruptives there is great variety. Their extravasation, beginning early in the Paleozoic, recurred vigorously in the Triassic and at the close of the Jurassic, and, finally, also in the Neocene and Pleistocene.

The dioritic rocks of the region are a portion of the great granitoid mass of the upper Sierra Nevada, and are evidently eruptive, with well defined contact phenomena in Triassic formations. Their eruption is certainly post-Triassic,* and may have taken place immediately at its close or after the deposition of the Jurassic.

There are at least four unconformities in the geologic column of the Taylorville region. Designated by the horizons between which they occur, they are as follows: Pleistocene-Neocene, Neocene-Jura, Jura-Trias, Trias-Carboniferous.

During the greater part, if not the whole, of the Paleozoic the sea covered the region now occupied by the northern portion of the Sierra Nevada.

The great disturbance at the close of the Carboniferous may have been accompanied by an uplift, forming land during the early Triassic; but if so, it subsided and was ready to receive the deposits of the upper Triassic.

The disturbance at the close of the Triassic formed no land in the northern Sierra region, but that which closed the Jurassic was accompanied by a great upheaval, excluding the sea to the western base of the Sierras.

The general structure of the Taylorville region involves a synclinal and two limiting anticlinals.

After the folds were overturned toward the northeast, the Grizzly anticlinal was affected by an overthrust fault in the same direction. The throw along this fault in the older strata is so much greater than in those of Jurassic age as to suggest that a large part of the displacement took place at the close of the Triassic and was followed by movement on the same plane at the close of the Jurassic.

*On this point see also "Notes on the Early Cretaceous of California and Oregon," by G. F. Becker: Bull. Geol. Soc. Am., vol. 2, p. 206.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 395-412

JURA AND TRIAS AT TAYLORVILLE, CALIFORNIA

BY

ALPHEUS HYATT

ROCHESTER
PUBLISHED BY THE SOCIETY
JULY, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 395-412 JULY 15, 1892

JURA AND TRIAS AT TAYLORVILLE, CALIFORNIA.

BY ALPHEUS HYATT.

(Read before the Society December 29, 1891.)

CONTENTS.

INTRODUCTION.

The results given in this paper are preliminary, but it will be seen by those familiar with such researches that my opinions, although for obvious reasons here considered as provisional and therefore subject to revision in final publications, have been based upon abundant materials. These consist of four different collections: The first was made by Mr. I. C. Russell and by the author and his son in the summer of 1888, and

showed the existence of the Lias* and Oolite in mount Jura, near Taylorville, Plumas county, California, and the need of making further researches in this locality. The second was gathered by Mr. J. S. Diller and the author in the summer of 1890, and this, together with a third collection made during the same season by Dr. Cooper Curtice, demonstrated the existence of a distinct fauna in the Hinchman tuff. It is only just to add that Dr. Curtice was the first to find this fauna at the locality named by Mr. Diller *Curtice cliff*. The fourth was collected in the field season of 1891 by Mr. Diller and the author, assisted by Mr. E. G. Paul and James Storrs. This enabled us to define the different faunas more exactly and brought to light, in a locality discovered by the indefatigable exploration of Mr. Diller, an additional fauna in the Bicknell sandstone. The success and accuracy of the results attained in such a difficult field and in so short a time are due to the exertions of Mr. Diller, who surveyed the surface minutely, leaving literally not the smallest outcrop unexamined; and his hearty coöperation and sympathy with the work of the paleontologist cannot be repaid by this formal public acknowledgment. The author desires also to take this opportunity to return his thanks to Mr. I. C. Russell for similar favors during the summer when they were associated at Taylorville and in the more extended exploration of the known localities of the Jura and Trias at the west.

So far my experience with geologists has demonstrated that by coöperation the paleontologist gathers larger and better collections in the same time, being freed from the need of doing strictly geologic work, while the geologist reaps a reciprocal advantage in being able to devote himself more exclusively to his own department. There is also a mutual exchange of criticism and information arising from the intimate relations of the work done in both departments which has a decided influence on the amount and quality of the results. The time saved is very considerable, since it frequently happens that a new locality indicated by a few fossils picked up by the geologist or one of his party can be at once explored and the value of the evidence ascertained on the spot; whereas had the fossils been taken home for examination, either they would fail to justify any definite conclusions with regard to the age of the rock or else be the occasion of another visit to the same place, involving sometimes considerable expenditure in money and time.

Many of the species are not yet named, but in all possible cases their European congeners are cited; and this is quite sufficient for the purposes of this preliminary notice, which was written in order that Mr.

*Professor Jules Marcou had in his article "Géologie de la Californie" (Bull. Soc. Géol. de la France, ser. 3, vol. xi, 1883, p. 111) stated that the Hardgrave sandstone was Liassic.

Diller's geologic essay might be read in connection with the paleontology, so far as his work and mine cover the same ground.

THE TRIAS.

Discovery.—The abundance and good preservation of the fossils in the *Monotis* bed of the Swearinger slates was made known by the survey of California under J. D. Whitney, and they were accurately described by Gabb in the first volume on the paleontology of California. The Hardgrave sandstone was also found by this survey, and some of the fossils of this bed were described by Meek in the same volume. One cannot praise too highly the work of these explorers and authors when the great difficulties under which they labored, both in the field and cabinet, are taken into consideration. They established all that was desired at that time, the demonstration of the presence of the Trias and Jura in the Sierras; and this primary fact and the publication of the fossils also led to the explorations of which the results are given in this paper. If these last are in their turn equally suggestive and useful to our successors, they will have fulfilled all reasonable anticipations.

Swearinger Slates: Monotis Bed.—The first and oldest fauna of the Trias was found at the locality made known by the California survey near Robinson's ranch.* These slates were filled with shells of *Monotis subcircularis*, Gabb, a species so close to the typical *M. salinaria*, Schloth., that I have grave doubts if it be really a distinct species. So far, at least, I have failed in finding any differential characteristic.

The fossils of *M. subcircularis* are closely compressed, and the species grew in banks, as did its congener in limestones at Hallstatt, though its habitat must have been a clay bottom. The *Monotis* is accompanied by *Pecten deformis*, Gabb, which is, however, not abundant. *Hemientolium (Posidonomya) daytonensis*, sp. Gabb,† is an equally rare species, and *Modiola triquetraformis* is still rarer.

Daonella Bed.—In the upper part of the same slates and closely underlying the limestone there is a fauna differing somewhat from that of the slates below,‡ comprising—

Monotis subcircularis, Gabb, rare.
Daonella tenuistriata, n. sp., rare.

---

*This or some neighboring establishment was then called Gifford's ranch.

†This is the type of a new genus, which I have called *Hemientolium*. The young until a comparatively late stage has the straight hinge line given in Gabb's figure (Geol. Surv. Cal., Pal., vol. i, 1864, pl. 6, fig. 32). Subsequently the anterior hinge line is developed into an acute ascending wing resembling the anterior wing of *Entolium cornutum* (sp. Quenst.) of the Jura, but no corresponding extension of the posterior wing is developed.

‡This is provisionally called the *Daonella* bed, but it is not yet positively ascertained that the fauna is separable from that of the *Rhabdoceras* limestone.

Hemientolium daytonensis, n. g., very rare.
Modiola triquatraformis, n. sp., well represented.
Avicula mucronata, Gabb, common.
Inoceramus (?) gerrillioides, n. sp., rare.
Pecten inexpectans, n. sp., well represented.
Lima acuta, n. sp., well represented.

This fauna therefore contains all of the species found in the *Monotis* bed below, but *Monotis* has become very rare, while *Modiola* is well represented. Among the remaining species, *Daonella* alone is peculiar to this level, and *Avicula mucronata* is characteristic, being found here as a common fossil, while both above and below this it is rare, and in the limestone it is, as a rule, smaller and of a different variety. *Inoceramus gerrilliodes* is also characteristic of this level.

Rhabdoceras Bed.—Immediately above the slates is a narrow band of limestone containing an abundant fauna which, however, could not be exhaustively explored on account of the fragmentary character and small extent of the superficial outcrops. It comprises—

Monotis subcircularis, Gabb, very rare.
Avicula mucronata, Gabb, very rare.
Pecten deformis, Gabb, very rare.
Pecten lasseni, n. sp., well represented.
Modiola triquatraformis, n. sp., well represented.
Myacites, n. sp., common.
Nucula tenuis, n. sp., common.
Lima acuta, n. sp., well represented.
Lima, sp. (?), a large, almost smooth cast.
Ostraea, sp. (?), one imperfect valve.
Inoceramus (?) simplex, n. sp., rare.
Rhynchonella solitaria, n. sp.
Arcestes californiensis, n. sp., common.
Halorites americanus, rare.
Ammonites ramsaueri, Gabb, rare.
Rhabdoceras russelli,* n. sp., rare.
Atractites, sp. (?), well represented.

The fauna of the limestone differs markedly from that of the upper slates and still more from the lower slates. It has all the species mentioned as occurring below, but they are all rare except *Modiola*, *Pecten lasseni* and *Lima acuta*. As additions we find to be abundant *Myacites* and *Nucula*, with a large *Lima*, an *Ostraea* and a *Rhynchonella*. There are

* Dedicated to Mr. I. C. Russell in memory of our work in the field.

some cephalopoda; *Arcestes* is abundant, and a species of *Halorites* appears. There is also the remarkable *Rhabdoceras*, a straight species of the Triassic ceratitinæ representing *Bactrites* among Devonian goniatitinæ, and *Baculites* among Jurassic and Cretaceous ammonitinæ. There is also one of the two primitive forms of belemnoids, *Atractites*, which is, however, represented by two fragments, each exhibiting the phragmocone and part of the guard.

All of these species, from *Monotis* to the cephalopoda, are forms more or less characteristic of the younger Trias, and if found in Europe would unhesitatingly be considered as belonging to the Noric series. After having expressed this as a provisional opinion in public, I found that Mojsisovics, who has done more than any one else to establish the subdivisions of the Trias on a sound basis, had already published the same opinion in considering the fossils described by Gabb in the paleontology of California.*

Halobia Bed.—Above the *Rhabdoceras* limestone lie unfossiliferous quartzites, but to the westward, near the top of the Carboniferous spur (so called on account of the presence of fossiliferous rocks of that system), we found a bed of slates containing *Halobia* occurring in banks as did the *Monotis* below on the Triassic spur.

These shells have the large anterior ear as in *Halobia rugosa*, a characteristic species of the upper Noric and lower Karnic series in the Alps, according to Mojsisovics, and there are some forms approximating to *Halobia superba* of the Karnic. The incoming of *Halobia* after *Daonella*, which occurs only in the upper part of the *Monotis* bed, suggests that we have here a fragmentary but parallel history to that in the Alpine Trias so thoroughly worked out by Mojsisovics. Thus, the *Monotis* and *Rhabdoceras* beds will probably prove to be characteristic fragments of the Noric series, while the *Halobia* slates and Hosselkus limestone of Diller may prove to be passage beds from the Noric to the Karnic series. These slates contain calcareous portions, and in a small mass of this kind a fragment of a species of *Tropites* occurred which was sufficiently well preserved to show the very peculiar form and similar markings to those of the well known lower Karnic species, *Tropites subbullatus*. This was accompanied by an *Arcestes* and fragments of *Atractites* identical with the species occurring above in the Hosselkus limestone. It is possible that the calcareous slates and their fossils occurred immediately below the Hosselkus limestone, but of this there are at present no positive proofs.

Hosselkus Limestone.—The Hosselkus limestone occurs above the *Halobia* slates on Carboniferous spur, and contains the same forms of *Atractites*

* Ueber Pelecypoden—Gatt. *Daonella* u. *Halobia*: Abh. d. k. k. geol. Reichsanst., B. vii. 1874, S. 1.

and *Arcestes*, together with a *Tropites* which may be the young of the species of this genus occurring in the *Halobia* slates. The forms comprise—

(I) *Arcestes-phylum* of *A. tornati;* Noric and Karnic.
" " " *A. galeati;* Noric.
" " " *A. bicarinati;* upper Noric and lower Karnic.
" " " *A. sublabiati;* Karnic.
Badiotites, allied to *B. eryx*, Mojsis.; upper Noric and lower Karnic.
Juravites, allied to *J. erlichi*, Mojsis.; upper Noric and lower Karnic.
Tropites, may be young of species occurring in *Halobia* slates; Karnic.
Atractites.

Arcestes (I) is very abundant, but whether the other forms are abundant or not it is difficult to say at present. The materials gathered show that the rock is full of fossils, but these cannot be obtained in any reasonable time by means of surface work. Besides the species mentioned, there is a form of *Acrochordiceras*, with finer costæ than those occurring in the Muschelkalk, a possible *Balatonites*, like *B. waageni* of the Noric, and some other fragments of ceratitinæ, all indicating a fauna rich in ammonoids, which will some day yield a good harvest to patient work.

General Remarks.—The results of explorations made up to the present time admit of some general comparisons, which, although by no means conclusive, are suggestive and interesting.

The Trias of Idaho (Aspen mountains, near Soda springs) has a well marked Triassic fauna, with fossil cephalopods recognized in Europe by Mojsisovics, Steinmann and Karpinsky as belonging to the lower part of the Triassic system, and, after careful re-examination of the fossils, I find strong grounds for thinking that this opinion is probably correct. This fauna appears to be more nearly the equivalent of that of the Werferner beds of the middle Buntersandstein of the German Trias than of any other.

The Trias of the Star Peak range in the Humboldt region, Nevada, contains an unmistakably younger fauna. Before reading the similar opinion of Mojsisovics, published in his superb work "Die Cephalopoden der Mediterranean Trias-Provinz," I had arrived independently at the same opinion, that this fauna belongs to the Muschelkalk and not to the younger Saint Cassian stage, as formerly supposed. When the species are properly published the parallelism with the Muschelkalk will be readily seen, since well preserved cephalopods are abundant.

The Trias of Taylorville is quite as interesting as that of the other two localities, and it is very suggestive that its age, as indicated by the fossils, is that of the Noric and Karnic series in the upper Trias.

THE JURA.

Lower Jura or Lias (Hardgrave Sandstone).—The Hardgrave sandstone contains the remains of a very abundant fauna and the fossils are sufficiently well preserved.

The most abundant species are the following: *Pecten acutiplicatus*, Meek, is to be expected wherever this sandstone occurs and can be called its characteristic fossil in this region: *Entolium meeki* is perhaps the next in abundance and is almost as widespread in distribution; *Pinna expansa* is not found everywhere, but it forms banks like *Ostrea* or *Unio* in some places and is often found associated with the two above named.

The age of the Hardgrave has been determined by cumulative evidence. That it was probably a member of the Lias, as previously stated by Professor Jules Marcou, became evident after a preliminary examination of the fossils, but the facts leading to the conclusion that it is more likely a member of the upper Lias than of the lowest Lias were more difficult of acquisition. It contains many fossils having affinities with those of the lowest or infra Lias, and the *Modiola* and *Mytilus* might even have occurred in the uppermost Trias or Rhætic. On the other hand, some forms have very close relations to the same genera as they appear in the Mormon sandstone, or Oolite, of the same locality. *Pinna*, *Gervillia*, *Ctenostreon*, *Entolium*, *Trigonia* and *Cidaris* show an assemblage of upper Lias types. The species of *Entolium* and *Ctenostreon* are closely related to those of the Oolite above, and one species of *Trigonia* resembles the young of a species from the Oolite of western Europe. The most conclusive evidence, however, is furnished by the single well preserved specimen of *Glyphea*, which I was so fortunate as to find in the typical locality close to the village of Taylorsville, and the *Goniomya*, allied to *G. v-scripta*, Agassiz.

The 42 species exhibited, which were selected from the collections of the Geological Survey, do not represent the entire fauna. I have still farther restricted the list given below to those species which are either characteristic or have been described and figured or can be closely compared with representative European species:

Taylorville, California.	*Europe.*
Montlivaultia, n. sp. (?).	*M. haimei*, Chap. et Dewal.; lower Lias.
Ostrea, sp.	*Ostrea irregularis*, Chap. et Dewal.; inferior Lias to middle Lias.
Ostrea, n. sp.	*Ostrea arietis*, Quenst.; lower Lias.
Anomia, n. sp.	*Anomia striatula*, Terq. et Piette; lower Lias.

Taylorville, California.	*Europe.*
Modiola, n. sp.	*Modiola psilonoti*, Quenst.: lower Lias.
Mytilus, n. sp.	*Mytilus psilonoti*, Quenst.; lower Lias.
Mytilus, n. sp.	*Mytilus terquemianus*, Chap. et Dewal.; lower Lias.
Pinna expansa, n. sp.	*Pinna hartmanni*, Auct.; lower Lias.
Gervillia linearis, n. sp.	*Gervillia lanceolata*, Quenst.; upper Lias.
Gervillia gigantea, n. sp.	*Gervillia aviculoides*, Quenst.; Oolite.
Gervillia gigantea, n. sp.	*Gervillia betacalcis*, Quenst.; middle Lias.
Lima, n. sp.	*Lima nodulosa*, Terq. et Piette: lower Lias.
Lima, n. sp.	*Lima charta*, Dum.; lower Lias.
Lima, n. sp.	*Lima galathea*, Dum.; upper Lias.
Ctenostreon, n. sp.	*Lima tuberculata*, Dum.; lower Lias.
Pecten acutiplicatus, Meek. *Lima sinuata*, " *Lima recticostata*, "	*Lima acuticostata*, Schübl.; inferior Oolite.
Pecten, n. sp.	*Pecten textorius*, Goldf.: Lias and Oolite.
Pecten, n. sp.	*Pecten dextilis*, Münst.: Lias and Oolite.
Entolium meeki, n. sp.	*Pecten demissus*, Goldf.; Lias and Oolite.
Goniomya, n. sp.	*Goniomya v-scripta*, Ag.; upper Lias.
Pholadomya, n. sp.	*Pholadomya ambigua*, Sow.; upper Lias.
Pleuromya, n. sp.	*Pleuromya striatula*, Dum.; upper Lias.
Trigonia, n. sp.	*Trigonia costata*, Sow.: middle Lias.
Trigonia, n. sp.	*Trigonia costatula*, Lycett: inferior Oolite.
Cidaris, n. sp.	*Cidaris*, Quenst.; upper Lias.
Glyphæa punctata, n. sp.	*Glyphæa solitaria*, Opp.; inferior Oolite.

I showed the unique fossil *Glyphæa punctata*, of which the carapace (with the exception of the tip of the rostrum) is well preserved, to Professor Walter Faxon, of the Museum of Comparative Zoology, well known as an expert carcinologist, and he at once placed it in the Jura under the name of *Glyphæa*. *G. solitaria*, Opp., of the lowest Oolite, zone of *Trigonia navis*, is not only very close to our American form in the characteristics

of the sutures of the carapace, but the surface has the rare sculpturing of punctation in place of the usual tuberculation found in most species of this genus, a peculiarity also characteristic of *G. punctata*. Such forms as these and the evidently close alliance and probable continuity of the fauna through migration with that of the Mormon sandstone suggest that the Hardgrave sandstone should be classed as upper Lias in spite of the large number of forms which are represented by species occurring also in the lower and middle Lias in Europe.

The homogeneous character of the rock and the association of fossils found in the larger masses of it led also to the conclusion that it represented only one bed in the upper Lias, but such minute researches as would have established this beyond question were not practicable.

Middle Jura or Oolite: Thompson Limestone (*Opis* Bed).—Mr. Diller's close and repeated investigations of the stratigraphy have placed the *Opis* bed below the Mormon sandstone in the chronologic series, and my studies, although they led me to incline to the opinion that the fauna was younger, have not succeeded in bringing to light any evidence that can be said to contradict his conclusions. The presence of a large form of *Nerinea* with the columella, showing the typical ridges of the normal forms of this group, indicate that this limestone is not older than the inferior Oolite, and if, as seems to be the case, it is older than the Mormon sandstone it will probably be proved to be a member of the inferior Oolite.

A large species of *Opis* is as abundant in some places as the *Nerinea*, and this genus, which is recorded in Europe as beginning in the Trias, is usually small throughout the lower and middle Jura. The only European species approximating to that of this limestone is the *Opis paradoxa*, as figured by Buvignier,* which occurs in the Corallian of the upper Jura. A species of *Terebratula*, apparently identical with the large characteristic species of the Mormon sandstone, also occurs abundantly in this bed. There are also a number of small gasteropods and other fossils requiring further investigation.

Mormon Sandstone (*Sphæroceras* Bed).—This bed contains the remains of a more varied fauna than that of the Hardgrave sandstone. In some places, especially upon spur 8 of Mr. Diller's map, the fossils are in excellent preservation; but in some localities merely superficial work does not give good results, the rock being apt to be very friable. Here as elsewhere the greatest treasures await resurrection at the hands of those able to dig deeply into the stony matrix.

It is more difficult to point out the characteristic fossils in this bed

*Stat. géol., min., métal. et pal. du Départ. de la Meuse, 1852, pl. 13, figs. 37-42.

than in the Hardgrave sandstone. *Lima dilleri* and *L. taylorensis*, *Ctenostreon*, *Trigonia* and *Entolium* are apt to occur in all the outcrops. So far as the determination of age is concerned, however, the ammonitinæ, although not abundant, afford the best evidence. These highly specialized forms, as has been pointed out by several of the most distinguished paleontologists in Europe, must have been extremely sensitive to the influence of the changes of the surroundings in passing from one geologic level to another, and have recorded these mutations in their own organizations. Even the encyclopedic Quenstedt continually expresses his satisfaction in turning from the uncertain indications afforded by the more generalized structures of other mollusca to the decisive chronologic evidence usually given by the fossils of this group. The list printed below contains a series of selected species, but many forms, especially among the smaller pelecypoda, which have not yet been studied, are necessarily omitted:

Taylorville, California.	*Europe.*
Terebratula.	*Terebratula perovalis*, Sow., as figured and described by Quenstedt, is similar, but the American species has no dwarfed varieties; inferior Oolite.
Rynchonella, n. sp.	*Rynchonella quadriplicata*, Zeit., as figured and described by Quenstedt; great Oolite.
Alectryonia, n. sp.	*Orthis marshii*, Goldf., as figured by Mor. et Lyc. in Oolite Mollusca; inferior and great Oolite.
Modiola subimbricata, Meek, and also other species of the same genus similar to this, but having shorter and broader shells.	*Modiola imbricata*, Sow., and other species of *Modiola*, with heavy umbonal ridges, occurring in the inferior and great Oolite.
Mytilus, n. sp.	*Mytilus sublævis*, Mor. et Lyc., and other species, having arcuate forms and heavy umbonal ridges, which are characteristic of the Oolite.
Pinna cuneiformis, n. sp.	*Pinna cuneata*, Phill., as figured by Mor. et Lyc. in Oolite Mollusca; inferior Oolite.
Pteroperna, n. sp.	Stands between *Pteroperna plana* and *Pteroperna costatula*, Mor. et Lyc.; inferior and great Oolite.

Taylorville, California.	*Europe.*
Gerrillia, n. sp.	*Gerrillia lanceolata* of the upper Lias, but longer and narrower in proportion, and the posterior wing larger. It is in fact a more progressive form in the same series of species than *Gerrillia lanceolata.*
Gerrillia. n. sp.	*Gerrillia ariculoides*, Sow.; great Oolite.
Lima dilleri, n. sp.	*Lima cardiiformis*, Sow.; great Oolite.
Lima, n. sp.	*Lima tenuistriata*, Münst. and Goldf.; inferior Oolite.
Lima taylorensis, n. sp.	*Lima rigidula*, Mor. et Lyc.; great Oolite.
Ctenostreon, n. sp.	*Ctenostreon pectiniformis*, Mor. et Lyc.: inferior and great Oolite.
Pecten, n. sp.	*Pecten disciformis*, Schübl.; inferior Oolite.
Pecten, n. sp.	*Pecten demissus-gingensis*, Quenst.; inferior Oolite.
Pholadomya. n. sp.	*Pholadomya fidicula*. Zeit.; inferior Oolite.
Trigonia. n. sp.	*Trigonia hemispherica*, Lyc.; inferior Oolite.
Trigonia, n. sp.	*Trigonia formosa*, Lyc.; inferior Oolite.
Belemnites, n. sp.	*Belemnites breviformis*, Voltz.; upper Lias to inferior Oolite.
Sphæroceras, n. sp.	*Sphæroceras gerrilli;* inferior Oolite.
Grammoceras, n. sp.	*Grammoceras toarcense*. as figured by Buckman; inferior Oolite.
Grammoceras, n. sp.	*Grammoceras leurum*, Buckm.; inferior Oolite.

The fossils indicate the former existence of a fauna which can be provisionally considered as belonging to the upper part of the inferior Oolite.

Inoceramus Bed.—Immediately above the Mormon sandstone with its rich fauna there are strata of a red sandstone containing very few remains and these usually in poor condition. Three species of fossils were found in them: a *Terebratula*, apparently the same as that occurring so plentifully in the typical Morman sandstone: two fragments of a large

species of *Inoceramus*; and a fragment of an ammonite of the genus *Perisphinctes*. The *Inoceramus* of the Jura is not so large in the Lias as in the Oolite, and these fragments appeared, therefore, to have belonged to shells at least as old as the Oolite. The specimen of *Perisphinctes* may prove to be identical with some species found below. It is probable, therefore, that this bed belongs, as in fact is indicated by the geology, to the upper part of the Mormon sandstone. On the other hand, the fact that one out of the three species was new to the fauna of the Mormon sandstone justifies a provisional separation under a different title on biologic grounds. Even if not sustained by future work, this distinction will serve a good purpose if it succeed in calling the attention of collectors in the same or other localities to facts that might otherwise escape their notice.

Upper Jura or Malm: Bicknell Sandstone (*Trigonia* Bed).—The fauna of the Bicknell sandstone is not so rich in species as are the Mormon and Hardgrave sandstones and the Thompson limestone, nor are the fossils so plentiful. The character of the rock in the surface exposures found by the party made it almost impossible to get out large specimens in perfect condition. Nevertheless, a sufficient number of molds of several large species of *Trigonia* (*T. obliqua* and *T. plumasensis*) and some well preserved specimens of *Gryphæa bononiformis* were secured; all of which are more or less characteristic of the youngest faunas of the Jura in Europe.

The remains of the ammonitinæ are fragmentary, but those that were found certainly indicate a somewhat older fauna than the species above named. There are a number of the molds of *Rhacophyllites* with the internal septa partly preserved, a fragment of a *Reineckia*, two rather poor molds of *Macrocephalites* (?), and several fragments of *Perisphinctes*. These form an association which gives strong support to the provisional opinion that the fauna is really synchronous with that of the Callovian, the oldest fauna of the upper Jura, or Malm, in Europe. The specimens of *Chemnitzia* are molds of a very large shell, but unluckily do not show the aperture. The only species in Europe which appears to be a close ally of this is also from Callovian.

The list below gives a very inadequate idea of the fauna, since none of the belemnites or ammonitinæ can be directly compared with European species on account of the need of more perfect specimens and are, with one exception, not mentioned. There are also a large *Nerinea* and a few species of pelecypoda and brachiopoda, which were not considered important in this preliminary notice:

Taylorville, California.	*Europe.*
Gryphæa bononiformis, n. sp.	*Ostræa bononiæ*, Sauv., as figured by de Loriol et Pellat; Portlandian.
Entolium costatum, n. sp.	
Oxytoma, n. sp.	
Trigonia obliqua, n. sp.	*Trigonia michelloti*, de Loriol; Portlandian.
Trigonia plumasensis, n. sp.	*Trigonia lusitanica*, as figured by Choffat; Portlandian.
Trigonia naviformis, n. sp.	*Trigonia navis*; inferior Oolite.
Chemnitzia, n. sp.	*Chemnitzia athleta*, d'Orb.; Corallian.
Rhacophyllites, n. sp.	

The group of *Trigonia glabræ* to which *T. obliqua* belongs reached its acme in the Portlandian, the species being both rare and comparatively small in the Lias and inferior Oolite. *T. obliqua* is of extraordinary size and shows the incomplete costæ of the Portlandian species. The group of *Trigonia* to which *T. plumasensis* belongs is very peculiar in the characteristics of the costæ and the ornamentation of the anal area, and it has hitherto been represented in Europe only by the unique form, *T. lusitanica*, found only in the highest Jura of Portugal. Besides these two large species there is also in *T. naviformis* an equally large representative of another peculiar and hitherto unique style of ornamentation. This, as its name implies, is similar to *T. navis** of the inferior Oolite in Germany, a species hitherto considered to be the only representative of a very distinct group, the *Trigonia scaphoidæ*, and having a pattern of costation not found in any other species (except *T. naviformis*) and a narrow chorologic range.

The group of the *Trigonia undulatæ* is represented by a species also of extraordinary size, but the *Trigonia clavellatæ*, the group more largely represented than any other in the inferior Oolite (if one can judge from the single specimen obtained in the Bicknell sandstone) is not materially modified.

Bicknell Tuff.—Above the sandstone and in immediate contact with it is a tuff described by Mr. Diller, which contains in part the same species as the sandstone, and the fossils indicate the same fauna. Nevertheless it should be noticed that it contained no remains of *Trigonia*, and that the fauna has not been critically examined.

Hinchman Tuff (*Stylina* Bed).—The presence of the same species of *Rhacophyllites* as that found in the Bicknell sandstone indicates the continuity of the fauna of this bed with that of the preceding; but, on the

*The differences between the two are quite sufficient to separate them as distinct species, but they have the same style of costation, especially on the anterior region.

other hand, the absence of *Trigonia* and the presence of close allies of *Ostrea bruntrutana* and of *Pecten suprajurensis*, shows that we have ascended in time to a younger fauna. The abundance of corals of the genus *Stylina*, these being the most widely distributed and characteristic fossils of the Hinchman tuff, shows that the age is probably that of the Corallian. In Europe these corals are rare in the Oolite, but reach their acme in numbers of species and forms in the Corallian of the upper Jura. The opinion expressed with regard to the age of the Bicknell sandstone is greatly strengthened by this fact, and it also adds to the evidence that the subdivisions of the Jura in North America and in Europe, like those of the Trias, may be compared much more closely than one would at first suspect from the extremely fragmentary records heretofore found in this country.

The fossils occurred in patches and, although abundant, good specimens were not easily obtained. The list is as follows:

Taylorville.	*Europe.*
Gryphæa curtici,* n. sp.	*Ostrea bruntrutana*, as figured by de Loriol; Corallian to Portlandian.
Camptonectes bellistriatus, Meek.	*Pecten suprajurensis*, Buvignier; Kimmeridgian.
Chemnitzia.	*Chemnitzia athleta*, d'Orb.; Corallian.
Rhacophyllites (same species as in the Bicknell sandstone).	
Stylina tubulifera.	*Stylina tubulifera*, Ed. et H.; Corallian.
	Astrea tubulifera, Goldf.; Corallian.
Stylina subjecta, n. sp.	Closely allied to a specimen in Museum of Comparative Zoology named *S. echinulata*, Lm'k.; Corallian.
Stylina alba, n. sp.	
Stylina minuta, n. sp.	Resembles the Cretaceous species figured by Goldfuss as *Astrea geminata* (equal *S. geminata*, Ed. et H.), but septa are not so symmetrical.
Stylina intermedia, n. sp.	
Stylina tertia, n. sp.	

Two species of *Belemnites* and a number of gasteropods, pelecypods and brachiopods were also found in this bed.

*I dedicate this important species to Dr. Cooper Curtice, the discoverer of this fauna.

General Remarks.—The discovery of the parallelism between the faunas of the Jura in India by Waagen, in Australasia by Moore and Etheridge, and in South America by Bayle and Coquand, Marcou, Gottsche, Steinmann, and the author of this paper, makes one more confident in deciphering the somewhat fragmentary remains found in these rocks, since everywhere homotaxial relations have been found to exist and it has been discovered that there is plainly parallelism in the evolution of the faunas on the different continents, enabling one to make close comparisons between the different series and often also even between the subdivisions or stages of those series, as has been done provisionally in this paper.

So far as the paleontologic researches have extended, they show that a series of fossil faunas exist in the rocks of Mount Jura, which approximately represent the three great subdivisions of the Jura, namely, the lower, middle and upper Jura; and these in their general faunal characters and associations of forms are, considering their wide removal from the European localities, not more distinct than one might very reasonably have anticipated.

All explorations have hitherto failed in bringing to light any very remarkable or entirely new types, such as have been found among the vertebrata on this continent. The general scarcity of the remains of vertebrates at Taylorville is another notable feature. A few fragments have been found, and possibly diligent and prolonged special research might bring to light more specimens and species, but they are not common, since the explorations, although confined to the surface, were thorough. This fact is applicable to the entire column of the Trias and Jura as heretofore explored along the western slopes of the Sierras and Andes, and it is probable that these faunas lived at some distance from the shores of the Jurassic continent and in a more open oceanic area than those of the Rocky mountain region or Europe, a conclusion in complete accord with the results of geologic research. In making comparisons between the Jura of Taylorville and that of Aurora, Wyoming, near Red buttes on the North Platte, and of the Black hills,* one is struck first by the fact that the latter were deposited in the same basin, the species being largely identical, as already demonstrated by Meek; and then, that they can be spoken of together as having the distinctive characteristics of the fauna of the Callovian or Oxfordian in the upper

* Localities near Northside, Bull Lake fork, southeastern Idaho, and on Aquarius plateau, Utah, have fossils apparently of the same fauna; but so little has been collected that one cannot speak with certainty. *Camptonectes* and *Ostrea*, found at various localities in Utah and described by Dr. White in the report on Explorations west of the 100th Meridian (vol. iv, part i) indicate the presence of similar fragments of the Callovian or Oxfordian at other localities in Utah.

Jura of Europe. A fine series of ammonitinæ collected at Aurora, Wyoming, shows the presence of the same species as those occurring at the Black hills, and other fossils are also identical. The genera to which they belong are all included in the group of the cardioceratidæ, under which name I unite the genera *Cardioceras*, *Cadoceras*, *Quenstedioceras* and *Neumayria*, all of them being peculiar to the Callovian and Oxfordian in western Europe and Russia. Although very often confounded with the amaltheidæ of the Lias, these genera have entirely different young forms and adult characteristics, especially in the sutures, and also have sprung from different ancestral radicals.

On going a step farther, however, and comparing the species* with those of the supposed Callovian of mount Jura it becomes evident that they have no species common to both; but, on the other hand, *Camptonectes bellistriatus* and possibly some other pelecypods and brachiopods are found occurring not in the supposed Callovian, but in the supposed Corallian of Plumas county. This unexpected result is in accord with the very distinct faunas of the Bicknell sandstone, or *Trigonia* bed, and of the Hinchman tuff, which do not permit us to suppose any very open or direct connection existed with the upper Jurassic faunas of the Rocky mountain region, and is in accord with the similar facts observable in the Oolite.

When attempts are made to compare the Oolite of the Rocky mountain region with that west of the Sierras, existing information with regard to the localities is found to be very imperfect. The Oolite certainly seems to have been found by Dr. Peale near the lower canyon of the Yellowstone in Montana, and out of the few fossils described by Dr. White some are closely similar to these of the inferior Oolite at mount Jura. *Modiola subimbricata* is apparently common to both faunas, and some of the species of *Gervillia* may be identical; but the species of *Trigonia* are entirely distinct from those of mount Jura.

Gasteropods and cephalopods have not been noticed in these Oolitic faunas. While this may be owing to insufficient collecting, it is well to note the fact; for although the remains of Oolitic ammonites have been occasionally picked up west of the crests of the Sierra Nevada, no such finds have thus far occurred east of that line, so far as known to me.

The lower Lias, containing characteristic ammonitinæ, one species of which (*Arnioceras humboldti*) was described in my "Genesis of the Arietidæ," occurs in the region formerly called the American district, Nevada,

* The entire absence of gasteropods from these deposits has been noted by Whitfield in his report on the fossils of the Black hills, and the same may be said with regard to the marine faunas at Aurora, Wyoming, and other localities mentioned above.

probably in the southern portion of the Star Peak range. There are also fossils in the collection of the mining bureau at San Francisco labeled as having been gathered in the Santa Fé district, Esmeralda county, Nevada, and Inyo county, California. These would not be worth mentioning were they not reported from places lying in the direction of the general strike of the Jurassic strata and also in perfect accord with the presence of *Arnioceras humboldti*. One species is a form of *Vermiceras* allied to *V. conybeari* of the faunas of the lower Lias in Europe, which I propose to name *V. crossmani*.* The second fossil, from Inyo county, was considered by me in the work already quoted to be identical with *Arnioceras humboldti*, but a reëxamination of the same specimens made in the summer of 1891 has satisfied me that this was an error. The pilæ are more closely crowded, and there are slight constrictions at intervals on the whorls of the nealogic (adolescent) stages. These disappear later, giving way to slightly arcuate costæ, which also differ from those of *Arnioceras humboldti*. I therefore propose for this peculiar form the name of *Arnioceras woodhulli*.† These facts all tend to the conclusion that the lower Lias, having certain forms of undeniable European facies, occurs in western and southwestern Nevada and perhaps in California east of the crests of the Sierra.

It is impracticable at present to discuss the relations of these faunas with those of the Lias on the western slopes of the Sierra Nevada further than to say that they are undeniably older than those found at mount Jura.

It is obvious, from all of these facts and others that might be mentioned, that the Jura occurs in widely separated patches, and that so far as now known mount Jura exhibits a larger number of fragments of the series of the Jurassic system than any other known locality in the United States, and that it was the best at which to make the first attempt to study this system in detail.

* The type is number 4989, collection of the State Mining Bureau, San Francisco, California, collected by J. H. Crossman. There is one specimen with the internal whorls and part of a living chamber in good condition, and two large fragments more compressed. It is a species having numerous whorls, as in the more generalized forms of the genus, straight numerous costæ without tubercles on the geniculæ, but the latter are prominent on the outer whorl and look as if they might have tubercles in later stages. The abdomen is channeled and keeled.

† The type is in the collection of the State Mining Bureau, San Francisco; number 7642, Inyo county, California, collected by D. S. Woodhull.

Tabular View.

Geologic Names by Diller.	*Special Biologic Names.*	*Similar Faunas in Europe.*
	JURA.	
	Upper Jura or Malm.	
Hinchman tuff........	*Stylina* bed..........	Corallian.
Bicknell sandstone.....	*Trigonia* bed	Callovian.
	Middle Jura or Oolite.	
Mormon sandstone.....	*Inoceramus* bed	Inferior Oolite.
	Sphæroceras bed	Inferior Oolite.
Thompson limestone...	*Opis* bed	Inferior Oolite.
	Lower Jura or Lias.	
Hardgrave sandstone...	....	Upper Lias.
	TRIAS.	
Hosselkus limestone...	....	Lower Karnic.
Swearinger slates	*Halobia* bed.........	Upper Noric.
	Rhabdoceras bed	
	Daonella bed (?)	
	Monotis bed	

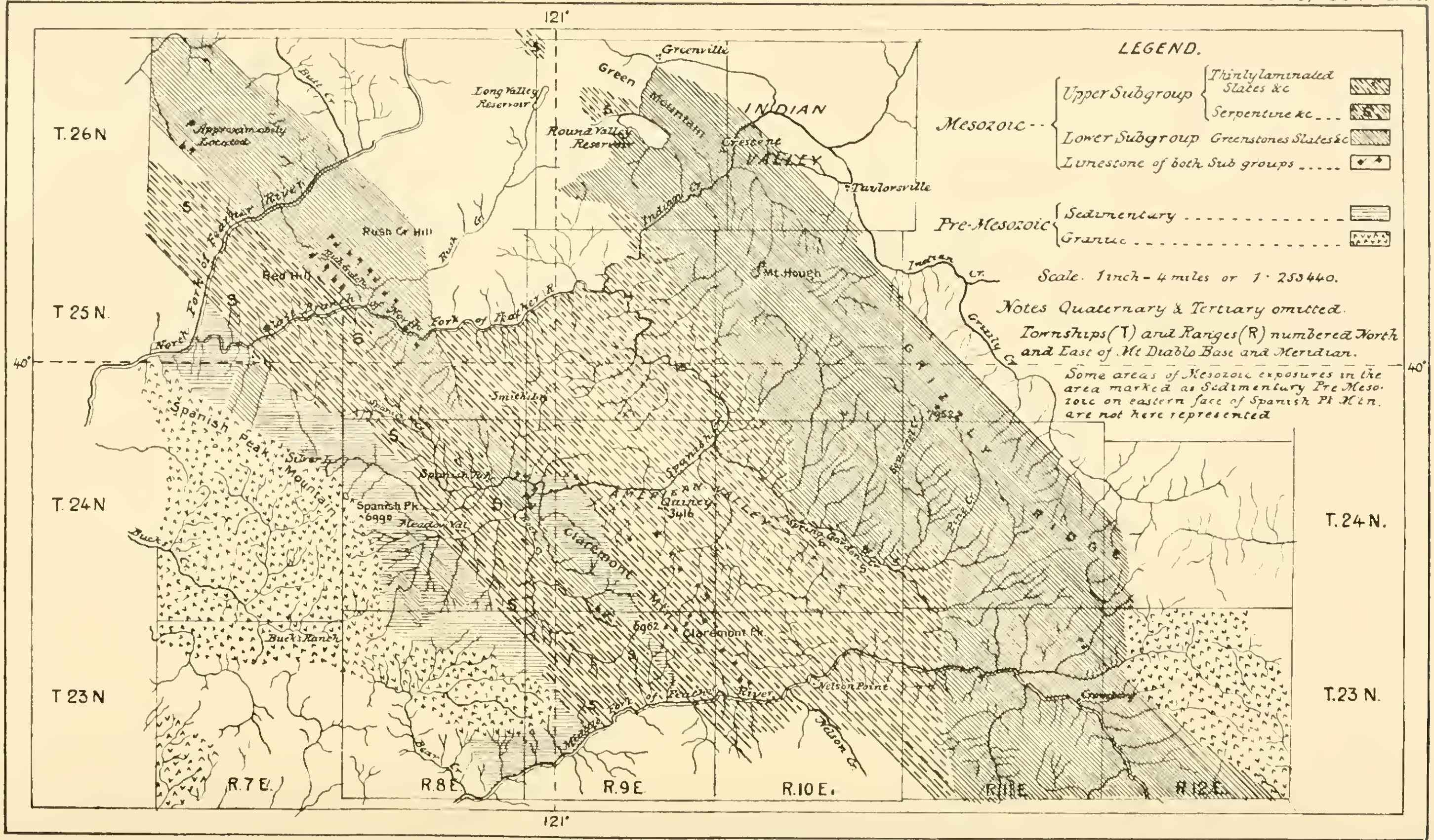
BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 413-444, PL. 13

STRATIGRAPHY AND SUCCESSION OF THE ROCKS OF THE SIERRA NEVADA OF CALIFORNIA

BY

JAMES E. MILLS

ROCHESTER
PUBLISHED BY THE SOCIETY
AUGUST, 1892



Sketch Map of PRE-MESOZOIC and MESOZOIC ROCKS, of a portion of the SIERRA NEVADA, between the North and Middle Forks of Feather River.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 413-444, PL. 13 AUGUST 8, 1892

STRATIGRAPHY AND SUCCESSION OF THE ROCKS OF THE SIERRA NEVADA OF CALIFORNIA.

BY JAMES E. MILLS.

(Presented before the Society December 29, 1891.)

CONTENTS.

Introduction.

General Character of the Sierra Rocks.—The great mass of the Sierra Nevada consists of crystalline rocks (granites) and highly metamorphosed, tilted and dislocated sedimentary and eruptive rocks. There are less metamorphosed strata of later age (Cretaceous and Tertiary) on the western flank at and near the foot of the range, and Tertiary and Quaternary lavas and sediments deposited by streams occur on the slopes and even on crests and peaks, especially of the northern half of the range. But the great mass of the range is made up of granites and of sedimentary and eruptive rocks so highly metamorphosed as to be quite generally designated as the metamorphic rocks of the Sierra.

J. D. Whitney showed in his report on the geology of California, and added confirmation in his work on the auriferous gravels of the Sierra Nevada, that a portion of these metamorphic rocks are of Mesozoic age, and in the same works he states, with less positiveness, however, that a part of them are of Carboniferous age.* The Mesozoic age of the rocks regarded by Whitney as Jurassic is farther confirmed by C. A. White and G. F. Becker, though White assigns them to a position at the confines of the Jurassic and Cretaceous periods,† and Becker places them higher up in the Cretaceous; ‡ but the limits of the groups of these rocks

*On identification of Mesozoic fossils by W. M. Gabb and F. B. Meek, and of Carboniferous fossils found outside of the Sierra proper by J. B. Trask and fragments of fossils found within the Sierra by W. M. Gabb.

† Bull. U. S. Geol. Survey, no. 15, 1885, p. 26.

‡ Bull. U. S. Geol. Survey, no. 19, 1885, pp. 9–18; also Bull. Geol. Soc. Am., vol. 2, 1890, pp. 201–208.

have not heretofore been defined, nor have the rocks within the groups been described with the order of their succession.

Division into two unconformable Groups.—By detailed examination of the rocks of one district within the range and comparison with those of other parts of it, I have been enabled to distinguish two unconformable groups definitely, and to determine the succession of rocks within the later of the two and partially within the older one, and, so far as my surveys have extended, to map the areas of exposure of each. The later group includes the rocks determined by Whitney to be Mesozoic, and, as will be shown hereafter, includes none other than Mesozoic. I shall call this group, for the purposes of this paper, the Mesozoic group, excluding from consideration the unaltered Cretaceous strata exposed along the western foot of the range.

The older group has thus far yielded no fossils within the Sierra proper, and I will designate it simply as the pre-Mesozoic group.

General Stratigraphy.

General Features of the Sierra.—Before entering upon a detailed consideration of the two groups and the succession of rocks within them, it will be well to present some general features of the stratigraphy of the range, for they throw much light upon the order of succession; and among strata so tilted, faulted and altered it is necessary to use all the means at hand to determine which are the higher or lower in the series.

The Sierra Nevada, as now defined, extends about 370 miles in a northwesterly direction, with the general trend of the coast of this part of the continent, from near latitude 34° 48′ to near latitude 40° 12′ north. At its southerly end it curves westward around the southern end of the valley of California, and coalesces with the Coast range. At its northern end it might be difficult, on purely geographical grounds, to distinguish it from the Cascade range; but geological considerations leave no doubt that the Sierra ends northward where its metamorphic rocks pass beneath the lavas of the Lassen peak district; for that mountain and the lava field stretching out southward from it occupy an area where, as late as the Chico (upper Cretaceous) epoch, the sea passed around the northern end of the Sierra, and where, as late as Miocene time, there was still a depression occupied by fresh water.* Other reasons, from structural geology, for thus limiting the range northward will be given hereafter.

Dual Character of the Range.—In its northern portion the Sierra is double, consisting of eastern and western divisions. The eastern division

*Geology of the Lassen Peak District, by J. S. Diller, in 8th Annual Report of the U. S. Geol. Survey, part i, 1889, pp. 395–432.

laps far southward by the southern end of the western, and is much the larger mountain mass of the two.* It culminates near its southerly end in mount Whitney, at an elevation of between 14,000 and 15,000 feet† above sea-level. Its crest falls northward and, as a continuous crest, terminates on the southern side of the Middle fork of Feather river. This division of the range continues, however, northwestward from that stream in broken sections to the edge of the great lava field west of Big meadows. Besides being separated by the depression of the Middle fork of Feather river, it is farther divided crosswise by the canyon of the East branch of the North fork and the canyon of the main North fork of the same river. It is known next north of the Middle fork as Grizzly ridge, then as Hough mountain or mount Hough, and north of the East branch of the North fork as Green mountain. It loses its distinctness as a topographic feature north of the East branch, and ends north of the main North fork west of Big meadows, near Prattville, where the metamorphic rocks pass under the Tertiary lavas. The ranges east of the main crest and of the mountains just named are here considered as belonging to the Basin ranges.

The western division is highest near its northern end, and is most distinct topographically between the Middle and North forks of Feather river.‡ It rises there to 6,990 feet above sea-level at Spanish peak. It falls rapidly southward and, as a topographical member of the present range, disappears, merging into the western slope of the eastern division. Geologically, it can be traced to American river, if not farther southward, by the outcropping of granite and other older rocks of the series. Still farther southward the main western division is replaced by two or more minor uplifted masses on the western slope of the eastern division.

The duality of the northern part of the range is a very important geological feature. Each of the two divisions has its own axes, or, more accurately, its own areas of habitual greatest uplifting; and before the Mesozoic upheaval the two were separated, at least during the period of subsidence that preceded the upheaval, by an arm of the sea.

Approximate Coincidence of successive Axes of Uplift.—The present relief of the range, or at least of the northern half of the range, is due princi-

---

*This duality was recognized and, in a general way, described by Amos Bowman in a paper on the "Geology of the Sierra Nevada in its Relations to Vein Mining," published in the 7th Annual Report on Mineral Resources west of the Rocky Mountains by the U. S. Commissioner of Mining Statistics, 1875.

†"Hence we conclude that it is highly improbable that mount Whitney should be less than 14,650 feet high." J. D. Whitney, in Auriferous Gravels of the Sierra Nevada, 1879, p. 28.

‡The western division of the range really lies along an extension southward of the axis of the Cascade range, and in a strict geological sense belongs to that range rather than to the Sierra proper; but it is probably impracticable to change the nomenclature so far as to make it conform to geological requirements in this respect.

pally to Tertiary and Quaternary uplifting,* but the axes of greatest uplifting of the present range coincide approximately with axes of uplifting of previous ranges within the same area. In other words, repeated orographic movements have taken place along the same axes, and recurring uplifts along these axes have followed recurring erosion. In this way a pre-Mesozoic range arose, carrying up both crystalline and metamorphosed sedimentary rocks, and partially disappeared through erosion and subsidence; then a Mesozoic range arose and its strata became uptilted, and it in turn was reduced by erosion and subsidence to very small proportions (in its northern half at least, nearly or quite to base-level of erosion) and then in Tertiary and Quaternary time has arisen the present range, which is now undergoing its erosion; but whether it is now rising or subsiding is not determined.

Position of Outcrops relative to Axes of Uplift.—The oldest rocks appear along the axes of greatest recurring or habitual uplifting, and as these are on the whole approximately coincident with the axes of the present range, the oldest rocks in a given section across the range outcrop quite generally along and near the crests and peaks of the present range, where they are not capped by Tertiary lavas and sediments, and on the whole the rocks highest in the series appear farthest from the crests. As already stated, the coincidence of axes is not complete, and the relative intensity or shear of uplift along the axes has varied greatly, as shown, for example, by the fact that the area of exposure of older rocks extends far southward of the crest of the western division of the present range. The succession is, moreover, frequently interrupted by faulting. However, the obscurity from these causes can be cleared away by noting the habitual or prevailing position of areas of outcrop of either of the groups of rocks relative to the axes or areas of greatest and least uplifting. The two principal axes of uplift are by no means the only axes of orographic movement; neither are the main or minor axes straight, unbroken lines. Each main uplift is made up of a series of uplifts, and the mountain masses are of very irregular shapes. They have, however, one prevailing characteristic, namely, that their longer axes have the trend of the portion of the range in which they occur.

The Tertiary and Quaternary uplifting to which the relative relief of the present range is due has been principally, if not entirely, by faulting. The history of the range includes also regional orographic movements, both of elevation and subsidence, the character of which has not been determined.

* This is abundantly proven by dislocation and uplifting of Tertiary and Quaternary deposits and by the obstructions to drainage which caused them; but I must leave detailed statement of proofs to a future paper.

Axes of greatest Uplifting.—A prevailing geographic characteristic of the range is that the crest of each of its two great divisions and of its individual mountains is near the eastern edge of the mass; in other words, the easterly slope is much steeper than the westerly one. The easterly slope may be called a fault-plane, though it is not by any means a simple plane, but a broken, jagged and irregular composite plane. The western slopes also rise in part, if not wholly, by faults; but they are, as a rule, of less shear, and form less prominent escarpments than those of the easterly slopes. This is not, however, a universal rule. The westerly slope of Grizzly ridge, for instance, rises from its foot by a fault, which I have called the Cromberg fault, which can be traced and measured by the dislocation of Tertiary deposits for over seven miles, and near the hamlet of Cromberg, on the Middle fork of Feather river (in sections 12 and 13, T. 23 N., R. 11 E., M. D. M.), the uplift is more than 1,100 feet vertically in 3,375 feet horizontally; how much more than 1,100 feet I cannot say, as the floor on which the Tertiary deposits rest at the downthrown (southwestern) side of the fault is not exposed.

Relative vertical Descent of eastern and western Slopes.—The descent of the eastern slope of the range as a whole is much less in vertical extent than that of the western slope; for the interior basin, at the foot of the steep easterly face, is much higher than the valley of California, at the foot of the westerly slope. The elevation above sea-level of Owens lake, at the foot of the easterly face, nearly east of the summit of mount Whitney and 12 miles distant from it, is 3,618 feet,* while Visalia, in the valley about 54 miles west of the summit of mount Whitney, is but 348 feet above sea-level.† Lake Tahoe is, according to Wheeler, 6,202 feet above sea-level, while the summit of Twin peak, about four miles away, is 8,824 feet, and the valley 54 miles west of Twin peak is 163 feet above sea-level.

Strike and Dip.—The metamorphic sedimentary rocks of the range are tilted to high angles with the horizon. The prevailing strikes are parallel to the general trend of the range and of the coast; the prevailing dips are between 40° and vertical, and the larger part of them between 60° and vertical. The direction of dip over much the larger part of the area is easterly; but in the northerly part of the eastern division of the range, namely, on Grizzly ridge, Hough mountain, and northward to the edge of the lava field, the prevailing direction is westerly, and north of the North fork of the Feather this direction of dip extends further westward.

Unconformity of the Mesozoic and pre-Mesozoic.—The strike and dip are but slightly affected by the Tertiary and Quaternary uplifting, and I

---

*Capt. Geo. M. Wheeler, U. S. Geographical Surveys West of the 100th Meridian.
†U. S. Signal Office Reports.

have not been able to discover any unconformity of dip and strike between the strata of the pre-Mesozoic and Mesozoic groups; but the strata of the two groups are unconformable by erosion. Those of the older group were raised above sea-level and eroded, and then subsided to receive Mesozoic sediments. Moreover, they, or at least some of them. were metamorphosed before the erosion, for pebbles and bowlders of pre-Mesozoic quartzites as well as granites occur in Mesozoic conglomerates, as will be hereafter shown. It is probable that the pre-Mesozoic uplifting was, like the Tertiary and Quaternary uplifting, principally by faulting, and therefore of little effect upon the prevailing dip and strike.

Epoch of Tilting.—The upper Cretaceous (Chico) and Tertiary strata at the western foot of the range dip westward at low angles. It follows, therefore, that the greater part of the tilting of the metamorphic rocks took place before the later Cretaceous strata were deposited and after the Mesozoic metamorphic rocks were deposited. According to Whitney's determination, the Mesozoic tilting was done at the end of the Jurassic; according to Becker's apparently tentative and still incomplete determination, it was later or "post-Gault."*

Character and Extent of Uplifting.—A part, at least, of the pre-Tertiary uplifting was by fault, for on the easterly face of Claremont (see accompanying map, plate 13) pre-Mesozoic rocks are brought into contact with the highest subgroup of Mesozoic strata. The displacement is in part Tertiary and Quaternary; but the extent of this part can be measured by the dislocation of Tertiary sediments and lavas. At one point at the northern end of Claremont the vertical relative displacement of the Tertiary materials is but 1,300 feet, while the pre-Mesozoic slates there are brought into contact with the thinly laminated shales of the upper part of the upper Mesozoic subgroup. The greatest relative vertical displacement of Tertiary deposits at Spanish peak and Claremont is but about 3,300 to 3,400 feet, while the shear of the fault is several times as great. How much of the pre-Tertiary uplifting is due to pre-Mesozoic and how much to Mesozoic movement I have found no means of testing.

How the Mesozoic uplifting and tilting was effected is not clear. With the prevailing easterly dips, later rocks are often carried beneath older ones; in other words, the strata have been overturned. The most ready inference is that the strata were thrown into anticlinal and synclinal folds by approximately horizontal thrusting, that these folds were overturned, and that during or after the folding the mass was faulted. But the slopes of the range are steep, and over a large proportion of the area the rocks are bare, and deep canyons afford numerous and extended vertical sections; yet neither arches nor inverted arches appear, and I know

* Bull. Geol. Soc. Am., vol. 2, 1890, pp. 201–208.

of no reason for assuming that there ever were such in the region. The conditions point rather to tilting of irregular blocks formed by approximately vertical or steeply sloping faults, and included within and separated from the surrounding mass by fault planes. Such blocks have been formed by Tertiary and Quaternary uplifting; indeed, the uplifting has been by blocks, and each mountain is a block. Moreover, as a rule the block is raised higher near one of the two longer edges (more commonly the eastern edge) than the other—that is, the block is somewhat tilted. If the pre-Tertiary faulting was principally Mesozoic, and the tilting of the blocks was carried farther than the Tertiary and Quaternary tilting until commensurate with the Mesozoic faulting, the present structural conditions would result—that is, the strata would be thrown on edge and those of any given block would be without connection by arches or inverted arches with corresponding strata of adjoining blocks.

The District more particularly described.

The district in which my studies and surveys have been most detailed lies between the eastern and western crests and between the North and Middle forks of Feather river, and as my most definite illustrations are from this district I shall describe it briefly.

The general topography and geology of the district are outlined on the accompanying sketch map (plate 13).* Grizzly ridge, Hough mountain and Green mountain form the eastern division of the range. Grizzly ridge and Hough mountain rise on the northeastern side by steep escarpment—a broken and jagged fault-plane—and on the southwest partly by steep escarpment and partly by slope, which however is steep. The slopes and escarpments meet at the top in a sharp crest. At the westerly side of the district rises Spanish peak mountain, which presents a very steep escarpment eastward; but its crest is the eastern edge of a plateau, modified by erosion, some 13 to 14 miles wide. From the westerly edge of this plateau the surface drops rapidly to the Great valley of California.

Between the two divisions of the range north of the Middle fork of Feather river rises an intermediate mountain called Claremont. There are also other ridges and mountains formed by uplift with axes of various directions—one running nearly eastward from Spanish peak mountain along the southern side of the East branch of the North fork of the Feather, and one between Spanish creek and the Middle fork, formed by a southwesterly uplift from Claremont, and a southeasterly one from Spanish peak. Detailed surveys have proved that the topography, which appeared at first sight to be the result of erosion and a simple system of

* Scale reduced from 1 inch = 4 miles to 1 inch = 6 miles, or 1:380,060, in reproducing.

uplifts, is in fact principally the result of a very complicated system of orographic movements. These are clearly shown by dislocations of Tertiary and Quaternary deposits which I have surveyed and mapped, but to describe them is not practicable within the limits of this preliminary paper. The main features for the present purpose are the eastern and western divisions of the range, the intermediate mountain Claremont, and the depression partly occupied by the American valley on the northeastern side of this mountain and Spanish ranch and Meadow valley on the southwestern side of it, which depression is drained by Spanish creek and its branches. Some of the principal elevations above sea-level are: Outlet of American valley, 3,353 feet; outlet of Spanish ranch, 3,618 feet; highest point on Grizzly ridge (barometrical), 7,952 feet; Spanish peak (barometrical), 6,990 feet; Claremont, 6,962 feet.

Pre-Mesozoic Rocks.

Eruptive Granite.—The principal exposures of the pre-Mesozoic rocks in the Sierra are the two areas of greatest uplifting already described. The eastern one extends from the southern end of the range to the northern flank of mount Haskell, between the North Yuba and the Middle Feather, where the pre-Mesozoic rocks pass beneath the Mesozoic. The western area of pre-Mesozoic rocks extends from the northern end of the range to the Great valley between Yuba and American rivers. Both areas include isolated and peninsular tracts of Mesozoic rocks.

The granites form by far the greater part of the pre-Mesozoic rocks; indeed, they make up the core and the great mass of the range and of each of the two divisions of the range. I have not seen granite overlying or penetrating sedimentary strata in the Sierra proper, but on the easterly slope of one of the nearer Basin ranges, a little south of Beckworth pass (which is at the head of the Middle fork of the Feather), there are dikes of granite penetrating gneiss. I must add that my observations of the granites have been, with few exceptions, limited to the northern half of the range.

Sedimentary Slates and Quartzites.—While the core and mass of Spanish peak mountain are of granite,* and the upper part of its eastern face is also of granite, lower down on this face, next to the granites, a series of slates and quartzites outcrop. The quartzites are evidently the slates, altered by silicification, for they retain the slaty structure, sometimes

* Professor A. Wendell Jackson, who kindly examined microscopically a specimen of this granite for me, wrote of it, October 22, 1888: "The Spanish peak rock consists of quartz, orthoclase, plagioclase, hornblende and biotite as essential constituents; this makes it a hornblende-granitite (after Rosenbusch). It is the most widely spread granitic rock in the Sierra, according to my present experience." It certainly is the prevailing granite of the northern half of the range.

laminated, but more often in distinct layers half an inch to an inch and more in thickness. The alteration occurs in all stages from that of somewhat siliceous slate to slaty quartzite and complete quartzite. The slates and quartzite are frequently contorted; the contortion being local and not caused by any general movement of the mass or by pressure from without, but by some locally acting force within the mass, probably molecular force accompanying the chemical and mineralogical changes of metamorphosis, causing alteration of volume and consequent displacement.

These pre-Mesozoic slates and quartzites lie on the granite, and were probably deposited upon it, as I have found no intrusions of the eruptive rock in the strata. They outcrop between the granite and Mesozoic rocks, and Mesozoic strata come in contact both with them and with the granite. It will be shown hereafter that fragments of both the granite and quartzite are found in a conglomerate of the lower Mesozoic group, and therefore that these rocks are older than those of that group and unconformable with them.

The Claremont uplift has brought to the surface a series of pre-Mesozoic strata. There are no granites or other eruptives among them, and they consist of highly metamorphosed slates. They retain more or less of slaty structure, though rarely cleavable into laminæ or sheets of considerable size, and they break with irregular, often more or less conchoidal, surfaces and into more or less prismoidal fragments. They are curled and contorted in much the same way as the slates and quartzites before described, but much more generally than they. There is a very general deposition or segregation of silica in the mass, evidently chemical. The silica is in part disseminated through the slate, but much of it is lodged in films on surfaces of cleavage or lamination, or in irregular bunches and lenticular bodies or veins, sometimes crossing, sometimes lying parallel with the surfaces of lamination. There are micaceous surfaces, and the mica and also an arrangement of the siliceous grains in the slaty laminæ sometimes give a gneissoid form to the rock; but there is not enough of mica or micaceous felting to form a true gneiss. The rock is sometimes chloritic, and some of the chloritic ledges have a massive form that suggests eruptive origin.

It will be shown hereafter that limestones and slates of the oldest Mesozoic subgroup of the district rest unconformably on these rocks. They are therefore older than the oldest Mesozoic rocks of the district. They are nowhere within this district exposed in contact with the granites or quartzites of Spanish peak mountain, and there are not any means here of determining directly the relative age of these and the Spanish peak pre-Mesozoic rocks; but farther northwestward, near the

northern end of the range, there is a nearly continuous exposure of the contact of granite and sedimentary pre-Mesozoic strata for at least seven miles from the West branch of Feather river, near the middle of T. 24 N., R. 4 E., M. D. M., northeastward along the divide at the headwaters of Kimshew creek. The sedimentary rocks approximate in character the pre-Mesozoic rocks of Claremont; they are imperfectly gneissoid and chloritic in part. Their strike is nearly at right angles to the prevailing strikes of the Sierra, namely, northeasterly, parallel to the contact just mentioned; and they dip at comparatively low angles northwestward away from the granite. They pass by the northern end of the western area of granite exposure here at the northern end of the western division of the range, as the Mesozoic rocks pass by the granite of the crest of the eastern division between the Middle fork of the Feather and the North fork of the Yuba. Across the area of outcrop of these strata on the northwestern side of it, about 4½ miles from the contact with the granite, at the Chaparral house on the Oroville and Prattville stage road, in section 10, T. 24 N., R. 4 E., are quartzites like those on the easterly face of Spanish peak mountain, with the ordinary northwesterly strike and a nearly vertical dip. The metamorphosed, imperfectly gneissoid and chloritic strata outcrop here between the granites and quartzites, and are probably lower than the latter. They may be contemporaneous with or older than the granite, although I have seen no intrusions of the eruptive rock in these strata.

There are quartzites in the range contemporaneous with the granite and imbedded with it. Such occur at and near the western edge of the granite of the eastern division of the range, where the South Yuba flows off it, between five and six miles east of the village of Washington; also in granites outside of the Sierra proper, north of Sierra valley, at headwaters of the Middle fork of the Feather. In both cases the quartzite is probably a product of alteration of the granite itself.

Pre-Mesozoic Rocks outside of upper Feather River District.—The pre-Mesozoic rocks of this district are not typical of the whole group in the Sierra, inasmuch as they do not include limestones which occur in great masses among the pre-Mesozoic rocks of the western flank of the range from the Mokelumne to near the Tuolumne river. These limestones occur in a group consisting principally of micaceous schists and quartzites, lying next to granite and in places surrounding isolated areas of this granite. Whitney describes the group in the "Geology of California" and also in his "Auriferous Gravels of the Sierra Nevada." On the Mokelumne, at the mouth of the North fork, I found an exposure of this limestone 400 feet thick in a series of mica slates which, becoming gneissoid, join the granite about two miles east of the limestone. Pre-

Mesozoic rocks continue west of the limestone on the Mokelumne about eight miles. From this exposure of limestone on the Mokelumne to the most southerly one described by Whitney is about 40 miles. These gneisses, mica-slates and limestones underlie unconformably strata known to be Mesozoic, but no fossils have been found in them and their age is not definitely determined.

About midway between the Calaveras and Stanislaus rivers in the Great valley, about three miles west of its eastern edge, is a small area of granite. It adjoins Mesozoic rocks on the east and passes westward under Tertiary deposits. It suggests an extension of pre-Tertiary uplifting of the western division of the range far south of the Tertiary and Quaternary uplifting of that part of the range. There is an area of pre-Mesozoic gneisses and other rocks between the Mesozoic outcrops and the Tertiary deposits of the valley on the Stanislaus and a much larger one south of the Merced, about Hornitas. The eastern area of granite comes forward to meet the Tertiary of the valley near where the San Joaquin comes out of the mountains,* and only isolated areas of sedimentary rocks are found on the western flank of the range farther southward.

Age of the Pre-Mesozoic Rocks.—I have treated the pre-Mesozoic rocks as of one group. It is not proven that they are all conformable or all of one period. It is entirely possible that a part of them are Archean and a part Paleozoic, and that the latter part may include rocks of different Paleozoic periods. Indeed, there remains a remote possibility that some of them may be early Mesozoic, older than the oldest group that is proved to be Mesozoic; but they are much more metamorphosed than these, are unconformable with them, and after having been deposited were certainly metamorphosed and uplifted, and the region had begun to subside again before the lowest known Mesozoic strata were deposited. It is not therefore within reasonable probability that any of these rocks are later than Paleozoic.

Besides being altered and tilted and faulted, the sedimentary rocks of this group are very widely overlain by Mesozoic rocks, and their outcrops are consequently disconnected; and fully to determine their order of succession will require examination and comparison of a large part of the areas of their exposure in the Sierra. The Mesozoic rocks, on the other hand, are not overlain except by comparatively thin Tertiary and Quaternary deposits, and therefore their sequence and natural division into subgroups are more readily determinable in spite of faulting, tilting, overturning and metamorphism. The district represented on the accompanying sketch map (plate 13) is a typical one for these rocks.

* According to map by Wm. P. Blake in his "Geological Reconnoissance in California," 1853.

Mesozoic Rocks.

PRINCIPAL DIVISIONS.

The Mesozoic group includes both sedimentary and eruptive rocks. The sedimentary rocks consist principally of slates often altered to quartzites, with, however, some limestones. The eruptive rocks may naturally, though rather roughly, be distinguished as medium basic lavas altered to diabase or greenstone, and very basic lavas more or less completely altered to serpentines. Both kinds are still further frequently altered to quartzites.

The whole group naturally falls into two subgroups, a lower and an upper one. The lower subgroup is characterized by a large proportion of the eruptive greenstones or diabases, while the upper one is characterized by deposits of serpentines, which in places attain enormous thickness. The proportion of eruptive matter in both subgroups varies exceedingly, and there is occasionally found a little serpentine in the lower division and greenstone in the upper one; but as a whole the two subgroups are characterized as stated.

Right at the confines of the two subgroups, but falling most naturally into the lower one, is a series of limy slates and limestones. These limestones are fossiliferous. The most numerous remains are of crinoidal stems, and, as hereafter shown, some of them belong to *Pentacrinus* or an allied genus, and cannot be of earlier age than Jurassic. We have, therefore, as a lower limit for the lower subgroup of Mesozoic rocks of the Sierra, the base of the Jurassic. They may, however, belong higher in the series. At the top of the upper subgroup is a long series of thinly laminated slates. I have found no fossils in these slates within the district of my more detailed examination represented on the accompanying sketch map lying between the North and Middle forks of the Feather; but comparison with exposures of similar slates south of Merced river (in Mariposa county) and at intermediate points proves conclusively that they are of the same horizon as the *Aucella*-bearing slates which Whitney, on the identification of F. B. Meek, determined to be Jurassic,* and which White places on the confines of the Jurassic and Cretaceous † and Becker assigns to a higher horizon in the Cretaceous (post-Gault). ‡

The fossils at these two horizons, one in each Mesozoic subgroup, show that the whole group is above the base of the Jurassic, and this is confirmed by an ammonite which, as hereafter shown, occurs at still another

*Geology of California, vol. i, 1865, p. 226.

† Bulletin of U. S. Geol. Survey, no. 15, 1885, p. 26.

‡ Bull. Geol. Soc. Am., vol. 2, 1890, pp. 201–208

horizon in the lower subgroup. I have not found any certain unconformity between these subgroups. The whole group seems to be one long series of sediments and lavas deposited during a period of prevailing though perhaps not uninterrupted subsidence of the region.

LOWER MESOZOIC SUBGROUP.

Slates, Greenstones and Limestones.—The greenstones or diabases of this subgroup are of eruptive materials, but these materials have quite commonly been transported to their present position and deposited there by water. Stratification is not infrequently visible, and the transition from massive greenstone to slate is sometimes gradual. The greenstone is very often and over wide areas conglomeratic, made up of bowlders and pebbles in a cement or groundmass of the same material, all of altered lava except at times a small proportion of fragments of quartz and other rocks. The bowlders and pebbles and groundmass have undergone much the same kind and degree of alteration, and the surfaces and outlines of the bowlders and pebbles are more or less obscure, but still are readily recognized on fresh fracture, and often more plainly on weathered surfaces. The bowlders and pebbles are well rounded. The mechanical condition and admixture of these materials are very similar to those of much of the Tertiary andesite, which has been transported by water and deposited in the same district, often on the greenstones. Between the South Yuba and the American, as well as between the Mokelumne and Calaveras rivers and elsewhere, lavas of this subgroup are exposed in dikes, where, to the naked eye, at least, they are not chloritic, but of dark-gray colors or black, sometimes porphyritic, and often very similar to Tertiary andesite. Professor Whitney says of this rock: "It appears from Mr. Wadsworth's (not yet completed) examination to be a diabase tufa, a much metamorphosed volcanic deposit. * * * Mount Bullion, Juniper ridge, Bear mountain (on the Merced) and Merced mountain are made up of this rock."* I have seen the exposures on mount Bullion and Juniper ridge, and the rock there is chloritic and largely conglomeratic, like the greenstones of the district under more immediate consideration here. On mount Bullion they are also largely altered to quartzite.

The greenstones and slates of the lower Mesozoic subgroup form the crest of Hough mountain and of the greater part of Grizzly ridge, though covered in part by Tertiary deposits. At the southeasterly end of Grizzly ridge they come in contact with pre-Mesozoic granite. The main eastern crest of the range is of these rocks from its northwesterly end south of the Middle fork of the Feather to the northwesterly flank of mount Haskell.

---

* Auriferous Gravels of the Sierra Nevada, 1879, p. 44.

Here and southward granite forms the crest where not covered with Tertiary materials, and the contact of these rocks and granite, passing down the westerly slope of this part of the eastern division of the range, crosses the North fork of the Yuba about 4½ miles east of Sierra city.

On the other (southwesterly) side of this northeastern belt of the lower Mesozoic subgroup its rocks come in contact with those of the upper subgroup. The contact crosses the East branch of the North fork of Feather river, here known as Indian creek, a little northeast of Shoofly, near the crossing of the line between townships 25 and 26 N., R. 9 E., then passes on to the westerly slope of Hough mountain and of Grizzly ridge, and crosses the Middle fork of Feather river between Bells bar and Nelson point.

In the upper part of this subgroup where it crosses the Middle fork of Feather river and thence a little east of southward to the North fork of the Yuba, one to two miles below Sierra city, are numerous outcrops of limestone. For the most part they and the rocks accompanying them are very much altered, and I have seen no fossils in them. In sections 11 and 14, T. 21 N., R. 11 E., are several masses of iron ore which seems to be a product of alteration of the limestone. Near the Yuba there is some serpentine associated with the limestone. These limestones undoubtedly belong near the boundary of the two subgroups, at the same horizon as the fossiliferous limestones to be hereafter described. Whether the outcrops of limestone recurring at intervals continue south of the North Yuba I do not know.

There is limestone exposed with a little serpentine in Little Long Valley creek in section 12, T. 23 N., R. 11 E. It is highly metamorphosed, and I do not know to what part of the lower subgroup it belongs. There is a little serpentine near the crest of Grizzly ridge not far from its northwesterly end. But nowhere in this large eastern area of exposures of the lower subgroup of Mesozoic rocks does serpentine occur in considerable mass. Near the crest of Grizzly ridge and near the divide between the waters of the Middle fork of the Feather and of the North fork of the Yuba and at the Sierra buttes both slates and greenstones of this subgroup are very generally altered to quartzites.

On the easterly face of Spanish peak mountain there are isolated areas of greenstones and slates of the lower Mesozoic subgroup resting on the pre-Mesozoic slates and quartzites.

The Claremont uplift has brought pre-Mesozoic rocks in contact with members of both Mesozoic subgroups, as shown on the sketch map, and far northwestward of the present Claremont mountain the same uplift has dislocated the rocks and brought those of the two subgroups into contact out of the regular order of sequence; so that the rocks of the

lower subgroup which have the serpentines of the upper subgroup on the southwest in the order of sequence, have slates of the same subgroup on the northeast by fault.

Fossiliferous Limestones.—In the last named area of exposure of the upper part of the lower Mesozoic subgroup occur the fossiliferous limestones. The outcrops are not continuous, but occur at intervals from a point on the southwestern flank of Claremont, in the N. E. ¼ N. E. ¼ section 4, T. 23 N., R. 9 E., to and across Spanish creek and across the East branch of the North fork of Feather river and the main North fork of the same river to the divide between Mosquito and Yellow creeks, in the western part of T. 26 N., R. 7 E., not far from the edge of the lava field at the northern end of the range. The whole distance from the southeastern end to the northwestern end of this line of exposures is about 19½ miles. From the southeasternmost exposure on Claremont to the divide between the East branch of the North fork of the Feather and the main North fork, a distance of 14¾ miles, I have made detailed examination and surveys of the area, including the outcrops of these limestones and of the rocks on either side. Thus examined and located, this long line of outcrops of fossiliferous limestones in the heart of the Sierra afford an available and definite horizon from which to measure and determine the position of rocks upward and downward in the series.

Jurassic or later Age of the Fossils.—The fossil remains are fragmentary, consisting principally of sections of crinoid stems, though fragments of brachiopod and gasteropod shells occur. Some of the crinoidal stem-joints are simple, round, and with round canal in the center; others, however, are pentagonal and have pentapetalous figures formed by crenated edges on the articulating facets. I sent some of these crinoidal stem-joints to Dr. Charles Wachsmuth, whose extensive and intimate knowledge of crinoids renders his identification of them most valuable. In a letter concerning these fossils, dated at Burlington, Iowa, November 18, 1891, he says:

"* * * I examined them carefully and have come to the conclusion that they must be at least of a later age than Triassic, possibly Jurassic. The stem-joints are pentangular, with straight sides or reëntering angles, and the facets in all of them have that peculiar petaloid structure which characterizes the pentacrinidæ, and which occurs in no crinoid preceding the Jurassic. Scattered between these stem-joints there are numerous smaller pieces with a central canal, which I take to be joints of the cirri, and of which in specimen 4 some are still attached to the edge of the joint. On that specimen I also find a few perforated arm ossicles with deep fossæ, showing a highly developed articulation of the arms, such as is rarely found in Paleozoic crinoids. The root on specimen 1 offers no special interest; the lines of union between the joints are serrated, but that is found even in some of the earliest crinoids. That the stem is round at the distal end does not prove that it

was round also in the proximal part, as the form of the stem changes greatly in its downward course, and it seems to me the upper face of the root shows traces of that petaloid structure to which I alluded. The other specimens show the same thing as number 4, but less distinctly. The genus *Pentacrinus*, which made its appearance in the Jurassic, survived to our present day; and as the structure of the stem remained almost unchanged, it is difficult to refer your specimen to any definite age, but I am quite certain they are not older than Jurassic." * * *

Mesozoic Conglomerate containing older Rocks.—The fossiliferous limestones alternating with slates and greenstones are at one point associated with a conglomerate containing pebbles and bowlders of granite and quartzite. The locality is on Rush creek, a little less than a mile in a straight line from its confluence with the East branch of the North fork of the Feather, in the northern part of section 8, T. 25 N., R. 8 E. The conglomerate is in contact with the limestone, and its cement is limy. The granite of the pebbles and bowlders is like that of Spanish peak mountain, and the quartzite like the pre-Mesozoic quartzites of the easterly and northeasterly faces of that mountain, and there is no other probable source of these bowlders and pebbles than within this westerly area of uplifting. It is plain, therefore, that the granite had cooled and crystallized, and the slates had been deposited and had undergone quartzitic alteration and been raised above sea-level and subjected to subaërial erosion, before these conglomerates were deposited on the beach of the arm of the Mesozoic sea. These rocks are therefore unconformable with the pre-Mesozoic strata, although no unconformity of dip and strike is apparent. I saw one granite pebble or bowlder of more than 500 cubic inches in size in the conglomerate.

The conglomerate is on the easterly edge of the limestones and limy slates, which are exposed for a width there of 5,300 feet and a thickness of about 4,600 feet. On the west of them and between them and the pre-Mesozoic rocks is the broad belt of serpentine three miles wide. I found no fragments of serpentine in the conglomerate. The serpentine, being an eruptive rock, may have been deposited on land or in water, but the slates and limestones were certainly deposited in the sea. If these and the serpentines had been deposited when the pebbles of this conglomerate were borne to the beach, they must have come across a width of some miles of water, unless the serpentines and slates had been uplifted. Of this there is no evidence; and as it is not possible that this beach material came across an arm of the sea (one pebble of granite containing more than 500 cubic inches), it follows that the conglomerate and the greenstones to the east of it are older than the slates and limestones and serpentines to the west of it. It is true that the serpentines now come in contact with the pre-Mesozoic rocks at the faulted easterly face of Spanish

peak mountain, but higher up on the face isolated areas of greenstones and slates occur and, as hereafter shown, the greenstones, slates and limestones come next to the same area of pre-Mesozoic exposures on the west between it and the Great valley, and in by far the greater number of cases throughout the Sierra the rocks of what I have called the lower Mesozoic subgroup outcrop between the serpentines and slates of the upper subgroup and the pre-Mesozoic rocks.

Unconformity on Claremont.—The fossiliferous limestones and accompanying slates lie unconformably on the pre-Mesozoic slates of Claremont. The contact and unconformity are plain to the eye where the road from Quincy to Oroville crosses the neck of the "Devil's elbow," on the left bank of Spanish creek, at the mouth of Rock creek, in section 18, T. 24 N., R. 9 E. The unconformity on Claremont is plainly by erosion, as no corresponding difference in dip and strike is apparent. There are greenstones and limestones and a little serpentine in isolated areas on and next east of the pre-Mesozoic area of this faulted northwestern end of the mountain mass.

UPPER MESOZOIC SUBGROUP.

Thinly laminated Slates and Serpentines.—The upper Mesozoic subgroup is the highest in the series of metamorphic rocks. Its exposures therefore lie generally in positions midway between the axes of greatest uplifting and between exposures of the lower subgroup on either side, the latter adjoining the pre-Mesozoic rocks still farther toward the right and left and nearer the axes of uplift. This prevailing order of succession on the surface is, however, often interrupted locally by faults. In the district here under more immediate consideration, the northeastern crest of the range is, as already described, of the lower Mesozoic subgroup; the southwestern crest and the face of the escarpment immediately below it on the east are of pre-Mesozoic rocks, with isolated areas of the lower Mesozoic greenstones and slates. Between the two mountains the greater part of the space is occupied with serpentines and slates of the upper subgroup. The slates occupy the eastern part and the serpentines the western part, and the two are separated by the long, narrow belt of protruding older Mesozoic and pre-Mesozoic rocks brought up by the Claremont uplift already described. As this belt approaches the Middle fork of the Feather it narrows and ends near the river, where the slates and serpentines of the upper subgroup come together. The area of exposure of the serpentines is from 1.6 to 3.5 miles wide, and that of the slates from 6.5 to 7.5 miles wide.

There is a narrow strip of serpentine outcropping on the easterly side of the exposure of slate, between it and the older Mesozoic greenstones

and slates of Grizzly ridge, along Spring Garden creek on both sides of it above the American valley (see sketch map, plate 13); but farther northwestward the serpentines are entirely absent and the older rocks brought into direct contact with the slates by faulting.*

There is another narrow strip of serpentine on the southwestern side of the slates at contact with the limestones and slates of the upper part of the lower subgroup, on the left bank of the East branch of the North fork of the Feather. There are also small isolated patches of serpentine on the faulted northern end of Claremont near limestone and slates of the lower Mesozoic subgroup and on pre-Mesozoic rocks. As the Claremont uplift dies out southeastward, hornblendic slates come in on the northeastern side of the pre-Mesozoic exposure, which belong to the serpentine series.

Where the succession is uninterrupted and where least interrupted by faults the serpentine joins the slates and limestones at the head of the lower subgroup. This is the case for 20 miles along the line of exposures of fossiliferous limestones before described. The slates at the head of the Mesozoic series, for reasons to be hereafter given, may be designated as the thinly laminated slates. Where the Mesozoic series is complete or nearly complete the serpentines and slates which accompany them lie between the thinly laminated slates and the rocks of the lower subgroups. It is plain, therefore, that in the ascending series the serpentines and the slates which accompany and replace them come before the thinly laminated slates, and that the latter are at the head of the whole series of metamorphic rocks of the Sierra.

Serpentine.—Throughout the area between the North and Middle forks of Feather river the lower part of the upper subgroup of Mesozoic rocks is almost entirely of serpentine, although there are some schists with it, and a part of these are glaucophanic. The schists may be made up of lava transported and deposited by water wholly or in part. South of the Middle fork the proportion of serpentine diminishes and slates increase. These slates are much like those of the lower subgroup and less thinly laminated than those at the head of the series.

The serpentine is for the most part plainly (to the naked eye) a product of alteration of a basic lava. The massiveness, cleavage and absence of lamination or distinct planes of stratification all go to prove this. M. E. Wadsworth describes, under the heading "peridotites," five specimens of this rock from Sierra and Plumas counties within the district next south of the one here more particularly treated of, and infers

* This line of faulting along the western foot of Grizzly ridge and mount Hough is a line of recurring orographic movements, as shown by dislocations of Tertiary and Quaternary deposits and obstructions to Quaternary drainage.

from the structure as seen under the microscope that the serpentine has replaced olivine and enstatite.*

Mr. J. S. Diller kindly gave me the results of microscopic examination of typical specimens which I took from the left bank of Spanish creek above the mouth of Rock creek and below Spanish ranch. He wrote of these January 25, 1887:

"Specimens numbered 1 and 2 are undoubtedly peridotites. Number 2 contains a great deal of olivine, but most of it has been altered to serpentine. Originally there was evidently a rhombic mineral, probably enstatite, associated with the olivine, but now it has all disappeared and serpentine with oxide of iron have taken its place. In specimens 1 and 4 no trace of olivine could be found; all has been altered to serpentine and magnetite; but the peculiar reticulated structure of the serpentine indicates clearly that it was derived from olivine. I have no doubt that these serpentines are altered eruptive rocks, peridotites."

These rocks can be found in all stages of alteration, from that of a dark gray or black trappean rock, sometimes porphyritic, massive, cleaving into irregular prisms, to that of an oil-green serpentine with conchoidal fracture and smoothed and rubbed or "slickensided" surfaces. It is sometimes fibrous. In a geological sense, the whole mass can most conveniently be designated as serpentine, but in a detailed lithological description it would be grouped under different heads according to original minor differences in the lava and to different degrees of alteration. A small proportion of the serpentine shows schistose structure and is more or less micaceous. Whether this is sedimentary lava or detritus of other rocks has not been determined.

The serpentine is in places altered to quartzite. Such quartzite after serpentine occurs at the outlet of Spanish ranch valley; also on Rock creek about three-quarters of a mile above its mouth.

Upper Slates.—These slates, as already stated, are at the head of the series of the metamorphic rocks of the Sierra. Wherever I have seen them freshly exposed by recent erosion or by artificial excavation they are of dark blue or bluish-black color and very commonly pyritous. The first effect of weathering is to cover the surfaces with red and yellow oxides of iron, frequently with efflorescences of alum; in later stages of weathering the red and yellow staining is removed and a light gray, nearly white, often powdery surface is left on the laminæ of the slate. When thoroughly weathered the slates show themselves very thinly laminated and fragile. At the outcrop this thin lamination is a distinguishing characteristic. They are very largely altered to quartzite, and the alteration is of a characteristic kind in this district. The result-

*Lithological Studies: A Description and Classification of the Rocks of the Cordilleras, 1884, p. 158.

ing quartzites are of two kinds; in one the siliceous rock retains the slaty felting and in part the slaty lamination, and this quartzite may be described as silicated slate; in the other kind the felting and lamination have disappeared and the siliceous mass is often partially or completely oolitic. The one kind passes into the other by gradation, sometimes within a few feet. There are no sandstones among the slates in this district, and I conclude that the difference is due to different kinds or degrees of alteration, and not to original differences in the sediment of which the rock was composed. The quartzites frequently pass by farther alteration into clear, white massive quartz. The quartzite is commonly dark gray when freshly exposed, but weathers to some shade of yellow or red from oxides of iron, and then to gray.

Limestones.—There are limestones in these slates, as shown on the sketch map (plate 13). They replace quartzites in the line of strike and are otherwise so associated with quartzites as to indicate that the latter have replaced the limestones, but lithological examination is necessary to determine definitely whether this is so.

MESOZOIC ROCKS OUTSIDE OF UPPER FEATHER RIVER DISTRICT.

Distribution of the Rocks.—The greater part of the Mesozoic exposures of the range are included within two principal areas, an eastern and a western one. The eastern and larger one begins at the northern end of the range and there includes its eastern crest, and extends in width westward to the western pre-Mesozoic area, as shown on the sketch map (plate 13). Farther southward it has the eastern pre-Mesozoic area on the east, and lies between it and the western pre-Mesozoic area, and continues so to the southern end of the latter. There it lies between the eastern pre-Mesozoic exposures and the unaltered Tertiary deposits of the valley for the greater part of the distance to its southern end, which is about 15 miles southeast of the Merced, where the pre-Mesozoic rocks come forward to the Great valley. Three minor arms of pre-Mesozoic exposures already mentioned lie between it and the Tertiary of the valley, one between the Calaveras and Stanislaus, one on the Stanislaus, and one south of the Merced about Hornitas.

The western principal area of Mesozoic exposures lies along the western foot of the range, between the western area of the pre-Mesozoic exposures and the unaltered upper Cretaceous and Tertiary rocks of the Great valley, and extends southward from the northern end of the range to where the granite of the western granitic area comes forward to the valley between the Yuba and American rivers.

Fossiliferous lower Mesozoic Limestones.—I have not seen the laminated slates of the head of the series in the western area, though there may be

outcrops of them there; but the serpentines of the upper subgroup and all the members of the lower subgroup are represented there, and among them the fossiliferous limestones. These occur near the contact with the unaltered upper Cretaceous (Chico) and Tertiary deposits, along the West branch of Feather river, at intervals from Nelsons bar bridge at the mouth of a creek coming in from the right, to near the mouth of Cherokee run above the bridge on the road from Cherokee to Yankee hill. Nelsons bar is in the N. E. ¼ section 7, T. 21 N., R. 4 E., and the mouth of Cherokee run in N. E. ¼ section 21, of the same township, according to a map of Butte county. These limestones are referred to as near Pence's ranch by Whitney, and on identification of imperfect specimens of fossils by Gabb, he called them Carboniferous.* They lie on both sides of the river, which here flows in a southeasterly course. They occur at different horizons in the section for about three-quarters of a mile in width of outcrop (dips, northeasterly at very high angle, or vertical).

At the northeasternmost outcrops, which are on the left bank of the river at Nelsons bar, serpentines are associated with the limestones. There are also serpentines further southwestward, but at the southwesternmost outcrops (all on the right of the river) the limestones are associated in places with greenstones, and a little farther southwestward the greenstones become massive and continuous and form the crest of a high ridge, on the southerly end of which is the village of Cherokee. These greenstones are largely conglomeratic. I found no fossils in the limestones on the left side of the river, but those on the right side of the river are commonly fossiliferous, the fossils consisting principally of fragments of crinoid stems. In my limited search I found no pentagonal sections of stems, but many that were round with round central canal, and some with lines radiating outward from near the canal.

These limestones lie about 34 miles directly across the western division of the range from the outcrops of limestone already described, stretching for 20 miles from the northern end of the range to Claremont. Here, as there, they lie in a series of slates, of nearly the same thickness in each case, between greenstones on the one side and serpentines on the other, with some greenstones associated with the lower limestones, and serpentines near the upper ones. It is true, I found no pentagonal crinoid stems in the limestone at the western foot of the range, but at some of the exposures between Claremont and the northern end of the range the sections of crinoid stems are also all round. I see no reason to doubt that these limestones, with accompanying slates, greenstones and serpentines, lying at the northern end of the range on the two sides

*Geology of California, vol. i, 1865, p. 209; Auriferous Gravels of the Sierra Nevada, 1879, p. 88.

of the western pre-Mesozoic area, so closely allied in lithological character, position, sequence and character of fossils, were deposited under indentical conditions, and are of the same age—Mesozoic.

About a mile southwest of the line of limestone outcrops. along the right side of the West branch of the Feather, in N. W. ¼ section 19, T. 21 N., R. 4 E., are two small exposures of limestone containing crinoidal fragments. A short distance westward the metamorphic rocks pass beneath Tertiary deposits, and consequently it is difficult to determine the exact position of these limestones in the series. It is probable, however, that a fault intervenes, and that these are of the same horizon as those along the right side of the West branch.

Eastern principal Area.—In the eastern principal area of Mesozoic exposures the broad belt of serpentine, though varying in width and possibly interrupted in places, extends from the northern end of the range to and across the Middle fork of American river. It therefore furnishes convenient means of connecting the exposures of this area generally as far south as to the last-named stream with those of the district already described. I have followed it from this district southward to midway between the Middle fork of the Feather and the North Yuba. It is credibly reported as crossing the North Yuba between Downieville and Goodyears bar, and this is confirmed by Professor W. H. Pettee.* Its eastern edge crosses the South Yuba at the village of Washington, the North fork of the American near Damascus, and the Middle fork of that river west of Michigan bluffs. Its western edge crosses the last-named stream in N. E. ¼ section 1, T. 13 N., R. 10 E. Here, at its western edge, is a large outcrop of pyritous talc.

I have not had opportunity to study the rocks next east of this serpentine belt farther southward than midway between the Middle fork of the American and the North Yuba. To that point the outcrops of thinly laminated slate continue from the district already described on the eastern side of the serpentine. From the South Yuba to the Middle fork of the American a broad area of the thinly laminated shales at the head of the series adjoins the serpentine belt on the west. At one place between the North and Middle forks of the American, where I have had opportunity to locate it roughly, the width is about 3 miles.

West of the area of exposure of thinly laminated slates again comes serpentine, with talcose rocks and slates, not in so wide an area as on the eastern side of the thinly laminated slates or so constant; still, exposures of serpentine with some talc are frequent, and they and the slates of the same horizon (lower part of upper Mesozoic subgroup) are probably constant from near Nevada city to the Middle fork of the American. How

* Whitney's Auriferous Gravels of the Sierra Nevada, 1879, p. 31

much farther they extend north and south of these limits I do not know. The serpentines show themselves on the railroad between Nevada city and Grass valley, and at the crossing of Greenhorn creek, and between there and the crossing of the Bear. On the same railroad, about a mile north of the Central Pacific railroad, is massive talc of the same horizon and very similar in character to that on the eastern side of the thinly laminated shales near the serpentines at the Middle fork of the American. Serpentines also occur west of the thinly laminated shales between the North and Middle forks of the American at a locality which is probably in section 13, T. 13 N., R. 9 E.

West of these serpentines and slates are exposures of the rocks of the lower Mesozoic subgroup, and they continue westward to the pre-Mesozoic gneiss and granite. The Central Pacific railroad crosses them from the contact with the gneiss about a mile southwest of Auburn to near Cape Horn. They consist largely of eruptive rocks (diabase), which have not here, as already stated, the prevailing chloritic character, but are of gray and black colors, sometimes porphyritic, and often resembling, to the naked eye, the Tertiary andesites. They often occur in dikes, traversing both slates and eruptive masses. East of Colfax, between it and Cape Horn, limestones occur, as they also do under Cape Horn, near the river. These limestones hold the same relative position at the head of the lower subgroup between the diabases or greenstones below and the serpentines above as at the northern end of the range.

Ammonites colfaxii.—One mile west of Colfax Professor Whitney found specimens of an ammonite which Gabb describes as *Ammonites colfaxii*, and referred with certainty to Mesozoic time and with some hesitation to the Liassic epoch. Whitney calls it a "secondary fossil."* It was found in the slates and diabases which underlie the limestones at the head of the lower Mesozoic subgroup. It is therefore from a somewhat lower horizon than the fossils found in the limestones at the northern end of the range, and this affords confirmation of the Mesozoic age of the limestones near Pence's on the West branch of Feather river.

Mesozoic Exposures south of the American.—From the South fork of the American to Sutter creek I have not had opportunity to examine the rocks.

From Sutter creek to the Tuolumne the area of Mesozoic exposures lying between the pre-Mesozoic rocks on the east and the Great valley on the west is approximately 12 to 15 miles wide. Within the area are two prominent axes of uplift, having the general trend of the main range, and along these axes, between the Calaveras and Stanislaus rivers, are two of the minor mountains above mentioned, the western one rising from the

* Auriferous Gravels of the Sierra Nevada, 1879, pp. 37–41.

edge of the Great valley, called Gopher hill, the eastern one Bear mountain. The valley between the two is 3 to 4 miles wide. Along the axes of uplift the exposures are principally if not wholly of the greenstones and slates of the lower Mesozoic subgroup. Between the long narrow belts of these exposures lie outcrops of the upper subgroup, and south of the Calaveras, if not north of it, the serpentines and slates and the thin slates of the upper subgroup occur again east of the easterly one of the two axes of uplift, followed by the greenstones and slates of the lower subgroup, which continue eastward to contact with pre-Mesozoic rocks.

Large masses of limestone occur in this normal position in the series at the head of the lower subgroup in places. The exposures of such masses are especially frequent between the Calaveras and Mokelumne and between the greenstones and lower slates brought up along the easterly one of the two axes of uplift on the east and the serpentines and their accompanying slates on the west. I found a fossil coral at one of the exposures at a limestone quarry on the road from Campo Seco to Mokelumne hill, a little less than 3½ miles from the former in a straight line, in the N. E. ¼ S. E. ¼ S. W. ¼ section 23, T. 5 N., R. 11 E.

A striking feature of this Mesozoic area is the great gold-bearing quartz lode called the "Mother lode." It occurs within the most easterly area of exposure of the lower subgroup, the one lying next to contact with the pre-Mesozoic rocks on the east. I have not had opportunity to determine its exact position in the subgroup north of the Calaveras, but between the Calaveras and Tuolumne it is, when present, at the head of the lower or greenstone-bearing subgroup and at or near contact with the serpentines and slates of the upper subgroup. At one place near Carson Hill village it passes over the line between the two subgroups a short distance and outcrops among serpentines and their accompanying slates.

Where the Tuolumne flows out to the valley at Lagrange there are greenstones of the lower subgroup and slates which are probably of the upper subgroup. Where Merced river comes out of the mountains at Merced falls the metamorphic rocks in contact with the Tertiary deposits of the valley are the thinly laminated slates at the head of the Mesozoic series. Farther southward, on the road from Merced falls to Hornitas, I saw a small isolated patch of these slates lying on pre-Mesozoic rocks.

Mesozoic Exposures south of the Merced.—East of the pre-Mesozoic area about Hornitas already briefly mentioned, and extending southeastward from the Merced about 15 miles to where the pre-Mesozoic gneisses and granites come forward to the valley, are two mountains, already noted; the western is called Juniper ridge, and the eastern mount Bullion. The

mass of both mountains consists, as before said, of greenstones and slates of the lower Mesozoic subgroup. The greenstones are largely conglomeratic and are largely altered to quartzite. In mount Bullion, at the west of the principal mass of greenstones, is a series of slates with limestones. Both slates and limestones are exposed on the Merced, and also nine miles southeast of the river. The limestones are siliceous, and no fossils have been found in them. Next west of these slates and limestones outcrop serpentines on both sides of the Merced and at points for 10 miles southeast. Farther southeastward they are replaced by talcose rocks, which probably belong to the same horizon as the serpentine, and these continue southeastward to the contact with pre-Mesozoic gneiss. The serpentines on the Merced are in part altered to quartzite, and this alteration is exhibited unmistakably and on a large scale on the right side of the river. Thinly laminated slates follow next west of the serpentines on the Merced, and they continue southeastward at least 11 miles. They form the floor of the narrow valley between the two mountains; at Bear Valley village the area of outcrop of these shales is about a mile wide. Here in these shales were found the *Aucella* and other fossils by which Professor Whitney established the Mesozoic age of this part of the metamorphic rocks of the Sierra. He, on the identification of Meek and Gabb, considered them Jurassic; while, as already stated, White places them at the confines of Jurassic and Cretaceous, and Becker places them still later in the Cretaceous.

There is faulting at the western foot of mount Bullion, as shown by excavations on the great quartz lode there. Professor W. P. Blake mentions a fault in the Princeton mine, which is on this lode 9 miles southeast of the Merced, in a report on the mine which I have not now at hand to refer to. It is plain from maps and reports of the mines, as well as from interruptions of the exposures at the surface, that the lode occupies a fissure at a fault plane. But the succession of the rocks, although obscured in places by the faulting, is essentially the same as at the northern end of the range.

THE MESOZOIC SERIES.

Natural Divisions.—The Mesozoic series is essentially the same throughout the two great areas of exposure, and is as follows in descending order:

Upper subgroup { Thinly laminated slates; Slates and serpentines.

Lower subgroup { Slates and limestones with some greenstones; Slates and greenstones or diabase.

The limestones of the series are not continuous and are frequently absent, and they occur in places elsewhere than in the third member of the series; but they are characteristically frequent and extensive in this member. The serpentines are also not constant in the second member, or the diabase or greenstone in the lowest member; but there is no very large area of exposure of the former without serpentine or of the latter without greenstone or diabase. Serpentine sometimes occurs in small proportions in the lower subgroup, and south of Sutter creek the greenstones are not entirely confined to the lower subgroup, but occur in small proportions among the serpentines and slates accompanying them of the upper subgroup, and possibly among the thin slates at the head of the series. There are also in the more southerly exposures of the thin slates some sandstones, and at one place near Montezuma, between the Stanislaus and Tuolumne rivers, I have seen among them a fine conglomerate. I have not found limestone among these thinly laminated slates except in the district described, between the East branch of the North fork and the Middle fork of Feather river. The non-chloritic character of the diabase in a part of the exposures shows a difference in degree or kind of alteration, and there are other minor differences. Still, there are enough distinguishing characteristics of the several subdivisions of Mesozoic rocks common to each throughout the areas of exposure to render it readily identified.

The division of the Mesozoic rocks into upper and lower subgroups simply brings out to view the characteristic eruptive activity and deposition at the different horizons. The principal eruptives in the pre-Mesozoic series are granites; in the lower Mesozoic, diabase or greenstone, products of alteration of a medium basic lava; in the upper Mesozoic, serpentine, a product of alteration of basic lavas. The succession of lavas in the Sierra in Mesozoic time is similar in one respect to that of Tertiary time, when the principal outflow of basalt followed the principal outflow of less basic lavas.

I have not attempted to give the thickness of the Mesozoic series or any of its members, as it is obscured by faulting; but data are accumulating which will, I trust, make it practicable to eliminate the errors from this source. The whole series is certainly several miles thick.

Fossil Horizons.—In three of the four natural divisions of the Mesozoic series fossils have been found, namely, in the thinly laminated shales at the head of the series (*Aucella*, *Belemnites*, etc. on the Merced, Mariposa county); in the slates and limestones with greenstones (crinoids with pentagonal stems, etc. at the northern end of the range); and in the lowest division, consisting of slates and diabase or greenstone (*Ammonites colfaxii*, on the Central Pacific railroad).

Alteration Products.

The quartzitic Alteration.—The details of metamorphism belong to lithology, but the quartzitic alteration is so general and on so large a scale in the Sierra that it becomes an essential and characteristic feature of the geology of the range. As before shown, there is quartzite after granite near the Sierra, if not within the range, and on a large scale after slates, both pre-Mesozoic and Mesozoic, and after greenstone and serpentines, and less certainly perhaps but to all appearance, to the naked eye, after limestone. In places the quartzite passes into pure white quartz. Quartz is found in lenticular masses and veinlets isolated from any fissure, in the quartzites and in the slates, and in fact in all the rocks, and such deposits of quartz are especially numerous in the pre-Mesozoic slates; and finally, quartz occupies much the greater part of the space between the walls of fissures throughout the Sierra.

Pyritous Character of the Rocks.—Another characteristic which is so prevalent that it cannot be omitted from a geological account of the range is the abundance of pyrite in the slates. From the outcrops alone no adequate idea of the proportion of pyrites could be obtained, but the more recent erosion and the tunnels and other mining excavations show a widespread distribution of pyrite throughout the slates. On account of the presence of pyrite, the slates weather to yellow and red colors at their outcrops; indeed, the color of the débris resting on the outcrops can be taken as an indication of the age of the surface—the débris on surfaces formed by more recent erosion is of gray color, while at surfaces as old as early Quaternary, or, more decidedly, as old as late Tertiary, the débris is of red and yellow colors. Of the pyrite in the greenstones or diabases I cannot speak with confidence; near fissures I have seen greenstone very pyritous. From the results of microscopic examination before quoted, it is probable that the iron in the serpentine is in the form of oxides rather than sulphides. Masses of chromic iron ore are found in the serpentine.

Fissures and mineral Veins.—Quartz, which is so large a product of alteration of the rocks of the Sierra, forms the great bulk of the material filling fissures, and pyrite, which is so widely distributed in the slates though in far less proportion than quartz, is much more abundant than any other mineral except quartz among the contents of fissures. The fissures are generally, perhaps always, at fault planes: they are effects of uplifting forces, and the mass on one side of each fissure is usually, if not always, uplifted farther than on the other. As already stated, the prevailing direction of the axes of uplift is approximately parallel to the strike of the rocks, and consequently this is true of the prevailing direction of

the fissures. But they sometimes run in other courses. Between the Middle fork of the American and the Yuba there is a series of fissures trending directly across the strike of the rocks. One of these, on Jamison creek at the Plumas Eureka mine, has yielded a large product of gold. At the same mine there are a number of so-called "flat veins" near and connected with the fissure, which are cleavage crevices enlarged and filled with quartz and pyrite containing gold.

Gold.—The occurrence of gold is not only most important economically, but is also a very important geological characteristic of the Sierra. The gold is associated with quartz, various sulphides (pyrite, chalcopyrite, galena, etc), and other minerals, but the essential accompanying minerals are quartz and pyrite. Gold mining in solid rock is called "quartz mining," and the treatment of gold ore consists principally in separating the valuable metal from quartz and "sulphurets." It occurs with quartz and pyrite both in fissures and outside of fissures where the quartz is a product of alteration of slates and other rocks, and its occurrence seems to be connected not only with the precipitation of quartz and pyrite in fissures, but also with the presence of pyrite and the quartzitic alteration in the rocks of the range generally. The richest deposits of gold in the solid rock, however, and all or nearly all that have been found rich enough to be profitably worked on a large scale in the Sierra are in fissures. The gold is very unequally distributed through the quartz of the fissure; frequently only a part of the thickness of the lode can be worked, and profitable mining, where it exists at all, is always limited to certain areas of the lode called "chutes" or "chimneys," and it would in nearly all cases effect a large saving of cost to find and use every available means of determining as early as possible the trend of the axes and outlines of these areas.

Gold-bearing fissures occur in both the pre-Mesozoic and Mesozoic rocks. In the granites gold quartz lodes have been found more or less productive, as at Granite basin, between the North and Middle forks of the Feather, also between the Sanislaus and Tuolumne south of Sonora and elsewhere, but I believe none such have been found far from contact with other rocks, and the great area of granite exposures, which includes much the larger part of the Sierra, has been barren ground for miners. In the pre-Mesozoic sedimentary rocks rich deposits have been found at and near Sonora, between the Sanislaus and Tuolumne rivers. These rocks are traversed by dikes of eruptive matter, which to the naked eye appears like the Mesozoic diabase, and the dikes were probably formed and filled in Mesozoic times. The gold occurs mostly in and near these dikes, and therefore it probably should be classed with the gold deposits of the lower Mesozoic subgroup. The pre-Mesozoic rocks of the district

south of Merced river, about Hornitas, have also yielded considerable quantities of gold.

Gold has been found in all the members of the Mesozoic series excepting the serpentine; but much the most productive part of the series and of all the rocks in the Sierra is what I have called the lower Mesozoic subgroup, which includes the slates and greenstones at the bottom of the Mesozoic series and the slates and limestones and greenstones next above. Nearly all of the deposits now most largely productive are in this part of the Mesozoic series, excepting some in fissures and dikes, which, though traversing older rocks, probably for reasons already given belong to the same Mesozoic age. As the lodes are generally if not always at fault planes, they are often at or near contact of this subgroup of Mesozoic rocks with others of a widely different horizon, as at Nevada city, where the contact is with granite.

Professor Whitney describes the before-mentioned great quartz vein, called the "Mother lode," extending (not continuously) from the Mariposa estate to Amador county, as "Made up of irregularly parallel plates of white compact quartz and crystalline dolomite or magnesite." * There is a large vein in the greenstone-bearing group on the southeastern flank of Spanish peak mountain, which also consists largely of magnesian limestone. The "Mother lode" between the Calaveras and Tuolumne rivers and also in Mariposa county south of the Merced, if not for its whole length, is at the head of the lower Mesozoic subgroup. This is the horizon of the fossiliferous limestones, and it is possible that the limestone of the lode where it occurs belongs to this group of sedimentary deposits, but it is also possible that it is a chemical deposit like the quartz.

The fact that the most profitably worked quartz deposits are in the lower Mesozoic subgroup does not prove that the rocks of that subgroup contain the most gold, but that they contain it in the form most available. In the other Mesozoic rocks (excepting the serpentine) and in the pre-Mesozoic sedimentary rocks there must be much gold in a more diffused condition, for the gravels which are débris of these rocks are often very rich. But I cannot here treat of the occurrence of gold further than as it is characteristic of the geology of the series and its several members.

Fissures containing Chalcopyrite.—In a long line of fissures near the western foot of the range, chalcopyrite occurs with the quartz and pyrite as an important constituent of the vein matter. The fissures are among or near the greenstones of the lower part of the Mesozoic series. Such deposits occur on the southern side of the Yuba, near Spencerville; south of Sutter creek, about 2½ miles south of east of Ione; on the Mokelumne,

---

* Auriferous Gravels of the Sierra Nevada, 1879, p. 46.

near Campo Seco; and between the Calaveras and Stanislaus in the valley between Gopher hill and Bear mountain, and also near the western foot of Gopher hill at Quail hill; and such deposits are reported as far south as in Mariposa county, south of the Merced. At Copperopolis, between Gopher hill and Bear mountain, they are worked on a considerable scale for copper, and on a smaller scale at two or three other points. Why this series of fissures along the western foot of the range should differ from the fissures in the same rocks on the western slope of the range generally in containing so much larger proportion of copper pyrites with the quartz and iron pyrites is not clear, but the fact is of geological significance.

Age of the mineral Veins.

The fissures are younger than the rocks they traverse, and consequently those that traverse Mesozoic rocks were made or extended after these rocks were deposited. The period of their deposition was one of prevailing regional subsidence, as already stated, but it was a period of great eruptive activity, as shown by the miles of thickness of diabases (or greenstones) and serpentines. It is hardly probable that all this eruptive activity took place without dislocation as well as fissuring. Moreover, there are strong indications of faulting at that time, especially at or near the boundary of the two Mesozoic subgroups, although no unconformity among the Mesozoic rocks has been certainly established.

At the end of the deposition of the metamorphic Mesozoic rocks there followed great uplifting, tilting and metamorphism, and certainly great fissuring. A prominent part of the metamorphism was the quartzitic alteration, which resulted in the production of quartz with pyrite and gold, like that in the fissures. It is practically certain, therefore, that a large part of the fissuring and filling of fissures in the Mesozoic rocks occurred with the tilting and metamorphism at the time when the deposition of these rocks ceased and they were raised above sea-level. A long period of subsidence followed, with little if any dislocation, continuing through the later Cretaceous (Chico), the Eocene (Tejon), and the early Miocene. Then followed the Tertiary and Quaternary uplifting, to which is due the relief of the present range. In these Tertiary and Quaternary movements there has been great faulting along lines of old fissures, and probably new fissuring; but we have gravels deposited by streams at the time of the early Miocene movements, and they are made up largely of quartzite and quartz with gold from Mesozoic as well as pre-Mesozoic rocks, and much of the quartz and gold is from fissures. It is therefore certain that a large part, at least, of the fissuring of Mesozoic rocks and the filling of fissures with quartz, pyrite and gold took

place at the time of the tilting and metamorphism of these rocks, and that possibly a part of it took place during their deposition.

It has been shown that the pre-Mesozoic rocks were raised above sea-level and a part of them had undergone the quartzitic alteration before the Mesozoic rocks were deposited. They were probably also more or less fissured while being uplifted and altered, and the fissures may have been at that time filled with quartz containing pyrite and gold. It is entirely probable that a part of the gold of the Sierra is of pre-Mesozoic age, and it is certain that a large part of it is of Mesozoic age.

A large proportion of the gold product of the Sierra has been obtained from Tertiary and Quaternary and Recent gravels, and is of Tertiary, Quaternary and Recent age, in the sense of having been detached, concentrated and deposited by streams of those times; but whether gold has been deposited in veins within the Sierra proper since the Mesozoic uplift has not been certainly proved or disproved. Professor Whitney saw a vein of chalcedonic quartz traversing Tertiary gravels,* and silica is not infrequently found forming a cement of such gravels, and silicified wood is not uncommon in them. There is chalcedony, evidently deposited by a now extinct hot spring, near the edge of a lava flow near Independence, south of the South fork of the Mokelumne. The fragments of chalcedony, resting on partially kaolinized slate, have been moved and washed for gold, but whether the gold was from the chalcedony or from the bed-rock on which it rested I could not learn in the short time spent there.

It is certainly not improbable that some gold-bearing quartz was deposited by the solfataric action that accompanied and followed the great Tertiary outflowing of lava; but the greater part of the gold-bearing quartz was deposited in veins older than the Tertiary lavas, for débris of such veins underlies the oldest of them.

*Geology of California, vol. i, 1865, p. 276; Auriferous Gravels of the Sierra Nevada, 1879, p. 330.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 445-452

THE GEOLOGY OF THE CRAZY MOUNTAINS, MONTANA

BY

J. E. WOLFF

ROCHESTER
PUBLISHED BY THE SOCIETY
AUGUST, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 445-452 AUGUST 8, 1892

THE GEOLOGY OF THE CRAZY MOUNTAINS, MONTANA.

BY J. E. WOLFE.

(*Read before the Society December 29, 1891.*)

CONTENTS.

TOPOGRAPHY.

The Crazy mountains are situated in central Montana, centering about latitude 46°, longitude 110° 15′. They form a high isolated range of the Rocky mountains, lying about 30 miles east of the easterly border of the main mass of the mountains, and rise abruptly from the eastern tablelands, attaining an extreme elevation of about 11,000 feet above sea-level. The Yellowstone river flows around their southern end a few miles after its exit from the mountains at the lower canyon, and the range is therefore in plain view from the Northern Pacific railroad for many miles eastward from the town of Livingston.

The mountains trend a little west of north and are about 40 miles long and 15 or 20 wide. A large branch of the Yellowstone, called Shields river, which flows southward along the western base, has cut a deep, flat transverse valley at its head nearly through to the eastward drainage, and there divides the range into northern and southern halves. Of the two portions thus defined the southern reaches the greater elevation. It has numerous sharp peaks, often of a jagged *aiguille* type, and the arrangement of the drainage is distinctly radial, since the streams flow westward, southward and eastward from the central mass of high peaks. In moving up one of these streams toward the head we find the valley at first comparatively broad, bounded by high bluffs of nearly horizontal sandstones,

which become cliffs as the spurs rise toward the peaks; but on approaching the central peaks the valley suddenly narrows for a mile or more and the stream falls from a higher level 400 or 500 feet by cascades and falls, and beyond this the valley again widens somewhat with a more gentle slope to the head. This "fall-line" is found on all the radial streams, and is plainly due to the local hardening of the Cretaceous rocks produced by the central stock of diorite, as described later.

The larger valleys have been occupied by glaciers, as shown by rock scoring; and the markings are found 500 or even 1,000 feet above the present stream levels. No lateral moraines were observed, but at the heads of the streams there is considerable morainic material, and also below the exits of the streams from the range, which here contains large bowlders of the characteristic eruptive rocks occurring higher up. The glaciation seems to have been entirely local. The broad benches, stretching out for miles eastward, westward and southward, are covered with water-worn pebbles from the range and may lie high above the present stream beds, which have cut deep through them into the underlying sandstones. The change in elevation from these benches to the spurs from the peaks is sudden, the difference of level between the base and the summit of the range averaging perhaps 4,000 feet.

That part of the mountains north of the head of Shields river is lower and the summits have the form of ridges or flat-topped dome-shaped masses. Both here and in the southern half, outlying peaked summits or buttes form a topographical feature.

General Structure.

The general geology is comparatively simple.* The range lies in a region of nearly horizontal Cretaceous rocks, extending indefinitely eastward in the great plains and westward to the edge of the frontal range, where sharp uplifts expose the older rocks. These Cretaceous rocks are found throughout the range and either horizontal or, if disturbed, with generally low dips. They consist of yellow or brown sandstones and occasional conglomerates, interstratified with yellow, drab, red, or black shales and impure calcareous beds. The conglomerates in one place contain large pebbles of an older (Carboniferous?) limestone; the shales, plant remains and small beds of impure coal. No attempt is here made to assign them to a definite horizon of the Cretaceous, but the base at least seems to belong with the Laramie, which a few miles westward has over 8,000 feet of strata.†

*J. E. Wolff: "Notes on the Petrography of the Crazy Mountains": Neues Jahrb. Min., etc, 1885, i, p. 69, and 1890, i, p. 192.

† W. H. Weed: Bull. Geol. Soc. Am., vol. 2, 1890, p. 360.

In the southern half the strata have a general inward dip at the outer edge of the range, both in the spurs and adjacent benches; so that gentle easterly dips are found on the western side, northerly dips on the south, and westerly dips on the east. In the interior this basin structure is interrupted by dome-shaped uplifts, of which the most marked is that connected with the central dioritic stock, from which the stratified rocks dip away with gently decreasing dips. This dome structure is sometimes repeated on a smaller scale in the outlying buttes. An example exists on the northeastern border between Little Elk and Big Elk creeks;* the shales and sandstones dip about 30° in three directions from the center of the dome, which has been eroded 300 feet lower than the sides, thus forming a roughly circular basin a mile or two wide surrounded by lines of cliffs. One small intrusive sheet can be seen in the upper strata, which rapidly thins out. Still farther outward from the center of the dome the strata have steep dips and contain numerous intrusive sheets or bedded dikes. The eroded center seems to be due to the lack of protecting eruptive sheets at that point, making it easy for the erosive agents to cut deep into the soft shales and sandstones.

In the northern half of the mountains the dome structure is developed with less regularity and a tendency to longitudinal uplifts with steeper dips and sharp crumples, producing long-crested ridges. An interesting case is found on the northern side of the deep transverse valley at the head of Shields river, consisting in the southern end of a long anticlinal dome, the strata dipping southward, eastward and westward within the space of a mile. They are here interleaved with numerous sheets of intrusive rocks, which curve around the sides of the dome with them and even preserve this parallelism in sharp minor crinkles a few hundred feet wide, by which the lines of outcrop make elbows. The present crest of the dome is formed by a master sheet or laccolite sixty feet thick, which dips off from three sides; but erosion has cut through it on the axis of the dome to the underlying soft shales, exposing to view a transverse dike of the same rock, apparently a feeder of the laccolite. The close conformity in greater and lesser crumplings between the intrusive and sedimentary rocks makes it necessary to suppose that the elevation took place after the intrusion of the former, for it does not seem possible that an intrusive rock could force its way into all the details of a sharply crumpled surface. This being the case, the eruptive rocks were examined with considerable interest at one of the sharp twists for signs of crushing, and with the expectation of some trace of the dynamic metamorphism so common in folded intrusive sheets of the Archean and

* The topographic map is not reproduced here.

Paleozoic; but neither in the field nor in the laboratory was any structure detected different from that of the rock under normal conditions.

The monoclinal buttes developed along either side of the range are very striking, especially on the western side. They owe their present elevation to the sheets of intrusive rock, which dip inward with the strata toward the range at varying dip angles in the different localities. The most important of these is the group of three high outlying buttes north of the head of Shields river ("Three Peaks" on the map), which are arranged *en echelon* on a north-south line, the crest lines of the two northerly ones lying progressively east of the third or southerly one. The strata dip about 30° eastward, and the three buttes have high cliffs facing westward and gentle dip slopes eastward. The crests are formed by heavy sheets or laccolites of intrusive rock from 250 to 100 feet thick, with minor sheets at intervals below, interstratified with the shales and sandstones. These master sheets bulge in the crest of the ridge, maintaining their thickness for about a mile in the case of the northern and southern buttes, and then rapidly thin out to a comparatively narrow bedded dike. Accompanying this diminution in size the crest of the ridge drops, and the next ridge, formed by another bulging sheet at a different horizon, begins, culminates, and dies out in the same way. This peculiar topography seems therefore due to the intrusion of bulging sheets (laccolites) at different levels in the horizontal strata, the major sheets not having their centers in the same vertical line; the whole complex was then tilted and eroded, the soft shales and thinner sheets being quickly taken off, leaving the master sheets standing. In the Henry mountains Mr. Gilbert has described the first conditions of intrusion without subsequent tilting.

Another peculiar type is found in the outlying butte near Martinsdale, on the northwestern edge of the range. This has an oval form, is about two miles long, and has an elevation of 600 or 700 feet above the plain at its base. It is fringed by a line of high cliffs facing outward, through which the interior drainage has cut an outlet. The top forms a basin with gently sloping sides. The Cretaceous strata are found around the base dipping gently inward, while the slopes and crest are formed by a great capping eruptive sheet and at least one lower sheet, with thin intervening beds of shale. The thickness of the great sheet was estimated at 365 feet and of the lower 150. In the center of the basin, on the summit, erosion has cut nearly through the main sheet, leaving tall pinnacles of the eruptive rock standing in groups (sometimes 50 feet high), which are due to the perfect vertical prismatic structure of the sheet. Loose pieces of metamorphosed shale found on the surface at the highest point seem to be remnants of the original covering of the laccolite. The erup-

tive sheets and basement shales have the form of a gently folded synclinal basin which erosion has spared.

Eruptive Rocks of the northern Area.

Structural Aspects.—The eruptive rocks are of great interest and novelty. They may be classified for purposes of description as dikes, sheets and laccolites, without any essential genetic difference. The writer has found no evidence of surface flows; all rocks appear intrusive and younger than the enclosing strata.

The dikes are innumerable and occur in every part of the range, varying in width and position. In the canyons cliffs of horizontal strata may be seen a thousand feet and upward in height, which are intersected by mazes of vertical and oblique dikes. Toward the interior of the range these dikes increase in number. As an example, a dike was counted every fifty feet horizontal on a long spur.

The sheets are closely connected with the dikes, which sometimes spread out between the strata as sheets, or a sheet may cut obliquely across the strata as a dike to another level. The sheets may be a hundred feet thick and a mile in extent. It is noticeable that sheets occur on the eastern and western edges of the range where dikes are rarer, and it seems to have been easier for the intrusion to force its way laterally. The facts indicating that many of the sheets have been folded with the strata after intrusion have been alluded to.

The laccolites differ from the sheets only in their greater thickness and bulging character. The greatest observed thickness of any one laccolite, free from shale bands, was about 350 feet, which would be increased to 500 if a thin shale parting were omitted. They have a well developed prismatic structure at right angles to the cooling surfaces, and hence the upright columns lean to correspond with the amount of dip. The tilted laccolites are, of course, best exposed, presenting cliffs on one side. The intrusion generally follows the bedding for some distance, but is liable to cut obliquely across, and without reference to joint planes. In one natural section a long splinter of shale 200 or 300 feet long and 30 feet thick is seen to have been bent off by the splitting of the eruptive mass, but is still continuous with the shales at one end.

It is rare to see feeding dikes below the laccolites. They are sometimes cut, in common with the shales, by later vertical dikes of the same or different rock which follow joints in the shales. A limited contact metamorphism is produced by the laccolites and thicker sheets at both contacts, by which the shales are indurated and often changed to a green color by caustic action. The changes in texture and even mineral composition produced by different conditions of cooling in the center and at

the contacts of the laccolites are striking. The rock has a coarse, often granitic, texture in the middle, but becomes dense and porphyritic within a few feet of the contact. The thinner sheets and dikes have throughout their mass the character of the contact varieties of the corresponding larger masses.

Lithologic Characters.—Brief mention should be made here of the varieties of eruptive rock thus occurring. The most prominent is a dark basic rock found in all three forms (the laccolites reaching over 350 feet in a single sheet), and having a coarse granitic texture in all but the dikes and thinner sheets. This rock, originally found here by the writer in 1883,* was found to be composed of feldspar (in part triclinic), augite and nepheline, with biotite, sodalite, magnetite, olivine, ægirine, etc, accessory; as an abyssal intrusive rock with the mineral combination nepheline, soda-lime feldspar, it filled a gap in the classification of Professor Rosenbusch, and was called by him "theralite," as the first undoubted representative of this family.

Associated with the theralite in parallel sheets or dikes are lighter colored alkaline rocks with a much higher content of silica, which in the thinner sheets correspond exactly in mineral composition and structure to the effusive rock called acmite-trachyte (often phonolitic) and in the heavy sheets resemble some eleolite-syenites (*e. g.*, those from Arkansas). Other sheets and dikes composed essentially of triclinic feldspar, augite, hornblende, or biotite appear to belong to various groups (diorite-porphyrite, camptonite, etc). The completed petrographical study of all these varieties is expected to bring out interesting relations between composition, structure and geological occurrence.

Features of the Southern Area.

The geology of the central mass of peaks in the southern half remains to be described. The radial drainage and "fall-line" features of the topography are due to the presence of a central mass or stock of coarsely crystalline diorite and granite, which has hardened and metamorphosed the Cretaceous strata for the distance of nearly a mile outward. The streams which head within the area of crystalline rock have to cut through this contact zone or ring of hard rock, beyond which they have cut deeper into the normal soft strata and widened their valleys. The diorite stock is irregularly oval in outline and is about 6 miles wide at the greatest diameter. The rock is composed of triclinic feldspar and hornblende, biotite, augite, hypersthene, often quartz and orthoclase, with the usual accessory minerals, but the composition varies somewhat.

* Neues Jahrb., op. cit.

The rock has a hypidiomorphous granular structure, is sometimes as coarse as a coarse gabbro, but near the periphery becomes fine grained and porphyritic and often has a marked parallel structure due to motion in the magma. A very basic coarse variety found near the center is noticeable. The diorite is cut toward the center by masses of a light-colored finer-grained granitite, which envelops fragments of the diorite. It is surprising to see the similarity between this Tertiary diorite and granite and the Paleozoic masses of similar rock found exposed on the old eroded surfaces of the Atlantic states, as, for instance, on the northern shore of Boston. In both cases the same black patches are seen in the granite, referable here to enclosed dioritic fragments, and the same alternations of basic and acid rock in streaks or "Schlieren" with parallel flow structure. The diorite is found in place in the streams as low as the 8,000 feet contour and can be traced 2,000 feet higher, remaining quite coarse.

The Cretaceous shales dip gently off from the dioritic mass as a dome, but at the actual contact were found sometimes turned up on edge and interlaminated with the diorite. They have been profoundly altered by the intrusive rock, preserving in general the stratification of the thicker bands but losing all shaly structure. The result is a dense flinty banded rock, creamy white, green, or black in color, resembling the contact rock called "adinole," or coarser, filled with biotite, and more like "hornfels," a product of Paleozoic granite contacts. None of the zones of mineralogical change so characteristic of the latter were observed. This effect extends out about 5,000 feet on all sides, gradually dying out, as certain layers only are affected.

The diorite stock as well as the adjacent Cretaceous rocks are cut by later vertical dikes of diorite-porphyrite and allied rocks; these dikes swarm in the contact zone, accompanied by horizontal and oblique sheets of similar rock. Mr. J. P. Iddings, who visited this place in 1891, finds that the vertical dikes, both in the stock and in all this part of the range, have a general radial arrangement, with the diorite mass as an approximate center, repeating a fact observed by him in a smaller diorite stock in the Yellowstone mountains. These long radial dikes extend outward even into the benches at the southern base of the range.

This imperfect description can give but a faint idea of the beauty of this great *massif* and its contact ring. Its intrusion into nearly horizontal late Cretaceous strata and the enormous subsequent erosion which removed the overlying rocks enable us to see it now in nearly its original condition with deep sections into its center, whereas in the older masses of granitic rock which we usually study the long-continued erosion and

movements of the crust have removed or altered many of the original features.*

The existence of this high range as an outlier is due to the facts that it was the center of violent eruptive activity in post-Cretaceous time, and that the presence of great masses of crystalline rock, combined with the honeycombing of the soft strata by dikes, enabled the whole mass to resist the erosion which levelled the adjoining country. The moderate uplifting of some of the larger sheets with their enclosing rocks also contributed to this result. Warren Upham calls it a striking example of the "eroded mountain range."†

It is hoped this sketch may present the claim of these mountains as a grand geological model and one, for the Rocky mountains, easily accessible. From Livingston or adjoining stations on the Northern Pacific railroad it is an easy day's drive to the foot of the range; the canyons of the larger streams on the east side are easily accessible by horseback and at the entrance even by wagon, and it is possible to ride to the falls in the contact zone. The outlying theralite buttes can all be visited by wagon.

*A smaller but apparently similar stock was observed in the northern half of the range, but not studied in detail.

†A Classification of Mountain Ranges, etc. Appalachia, vol. vi, no. 3, 1891, p. 204.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 453-541, PLS. 14-16

PROCEEDINGS OF THE FOURTH ANNUAL MEETING, HELD AT COLUMBUS, OHIO, DECEMBER 29, 30, AND 31, 1891

HERMAN LEROY FAIRCHILD, *Secretary*

(*With Index. Also Contents, etc, of Vol. 3, pp. i–xii*)

ROCHESTER
PUBLISHED BY THE SOCIETY
NOVEMBER, 1892

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 3, PP. 453-541, PLS. 14-16 NOVEMBER 9, 1892

PROCEEDINGS OF THE FOURTH ANNUAL MEETING, HELD AT COLUMBUS, OHIO, DECEMBER 29, 30, AND 31, 1891.

HERMAN LEROY FAIRCHILD, *Secretary*.

CONTENTS.

Session of Tuesday, December 29.

The Society met in the Hall of Representatives, State House; Acting President G. K. Gilbert presiding during the meeting. After the call to order at 10.15 a. m. and a few words of salutation, the Acting President introduced the Mayor of the city of Columbus, Honorable George J. Karb, who made a brief but cordial address of welcome, to which response was made by the Acting President.

Announcement was made that the report of the Council would be deferred until Wednesday morning.

The report of the Treasurer was presented in abstract by the Secretary. It showed a balance in the treasury, when the sum of $859.74 belonging to the permanent fund is deducted, of $280.74.

The Society elected as an auditing committee Messrs J. C. Smock and J. S. Diller.

ELECTION OF OFFICERS AND FELLOWS.

The result of the balloting for Officers, Fellows and amendment to the Constitution, as canvassed by the Council, was declared by the Secretary as follows:

OFFICERS ELECTED FOR 1892.

President:

G. K. Gilbert, Washington, D. C.

Vice-Presidents:

Sir J. William Dawson, Montreal, Canada.
T. C. Chamberlin, Madison, Wis.

Secretary:

H. L. Fairchild, Rochester, N. Y.

Treasurer:

I. C. White, Morgantown, W. Va.

Councillors, Class of 1894:

H. S. Williams, Ithaca, N. Y.
N. H. Winchell, Minneapolis, Minn.

Editor:

W J McGee, Washington, D. C.

FELLOWS ELECTED.

Garry Eugene Culver, A. M., Vermillion, S. Dak. Professor of geology, University of South Dakota; now engaged in artesian and underflow investigation of the United States Department of Agriculture.

Henry Gannett, S. B., A. Met. B., Washington, D. C. In charge of geographic work of the United States Geological Survey east of the 100th meridian.

The proposed amendment to the Constitution, making the Treasurer eligible to reëlection without limitation, failed for lack of three-fourths affirmative vote of the total membership.

A memorial of J. Francis Williams, prepared by J. F. Kemp, was read by the Secretary:

MEMORIAL OF JOHN FRANCIS WILLIAMS.

The name of Dr. J. F. Williams will always be associated in American geology with those of Newton, Irving and Lewis. His life, like theirs, was one of brilliant achievement, of great future promise, and of sad, untimely termination. Although his accomplished results were great, yet, coming as they did early in life, his friends could but regard them as indicative of the future, and there is thus, together with grief for his loss, the regret that so many possibilities are nullified. As he was one of the thirteen original Fellows who gathered at Ithaca in December, 1888, and organized the Geological Society of America, it is eminently fitting that some especial memorial of him should be presented.

John Francis Williams was born October 25, 1862, at Salem, the county seat of Washington county, New York, situated about forty miles northeast of Troy. He was the only son of John Martin and Frances A. (Schriver) Williams, who, with his one sister, survive him. His boyhood was passed at the beautiful family home until at twelve years he was placed in Saint Pauls School, Concord, New Hampshire. Leaving this in 1880, he entered the Rensselaer Polytechnic Institute at Troy. He completed the studies of the course in civil engineering and graduated in 1883 with the degree of C. E. Thus, like many geologists, he began his scientific work in the engineering school, but found his tastes inclining irresistibly to pure, as contrasted with applied, science. Although during August of 1883 he was assistant engineer of the Albany, Rutland and Granville railroad, in the following autumn he became assistant in chemistry and natural science at his alma mater. He was brought in especially close association with his teacher and warm personal friend, Professor Henry B. Nason, whose influence was largely instrumental in shaping his subsequent career. During this period he

made the tests of slates from the region about his home, the publication of which is subsequently cited. The Rensselaer Polytechnic Institute conferred on him in 1885 the further degree of B. S.

In the summer of 1884 he traveled in northern Europe, visiting North cape and the mines of Sweden and Norway. In the fall, acting on the advice of Professor Nason, he matriculated at the university of Göttingen and became one in a long and honorable list of American scientific men who have received their preparation at this ancient seat of learning. While at Göttingen his work lay especially in mineralogy and petrography under the guidance of Professor Carl Klein, now of Berlin, and in chemistry under Professor Victor Meyer.

In the spring vacation of 1885 he traveled with Professor Klein through Italy and Sicily, and later was assigned the subject of his doctor's thesis in one of the extinct volcanic districts of the former. Through Professor Klein, Dr. Williams came to know Professor Rosenbusch, of Heidelberg, to whose kind advice he was afterward indebted in his American work. Professor Klein received in Sienna several specimens of an igneous rock from Monte Amiata, an extinct volcanic pile that rises near the classic lake Trasimenus and forms the highest peak in Tuscany. They proved of such interest that they were intrusted to Dr. Williams as suggestive for his thesis. With characteristic energy and thoroughness he proceeded to the region in September, 1885, and, accompanied by a Swiss helper and a local Italian guide, he spent several weeks on the mountain, either camping or lodging in the little Italian inns.

Returning to Göttingen, he anticipated taking his doctorate in the summer of 1886, but the sudden call of Professor Klein to Berlin necessitated holding the examinations in the spring. He received his degree *magna cum laude*. The thesis was afterward published in the *Neues Jahrbuch*, and gained great praise in America as well as abroad. The paper is accompanied by four partial and twenty-two complete analyses of rocks, by an elaborate geological map, and by three panoramic views. Its special interest lies in the fact that it traces the differences in rock types throughout one great single eruptive mass, which is shown in its central part to be a trachyte containing hypersthene and labradorite, but which passes toward the borders sometimes into liparite, sometimes into andesite.

Professor Klein desired Dr. Williams to go to Berlin, become his assistant, and continue his career in Germany. For a time in 1886, this course was followed, but finally Dr. Williams returned to his home, and in 1887 became director of the technical museum of the Pratt Institute in Brooklyn. The duties consisted in arranging excellent collections of minerals and rocks, but the desire for wider opportunities for scientific

investigation led him in 1889 to take the position of honorary fellow at Clark university, Worcester. While in this relation he received overtures from Professor J. C. Branner which led to his undertaking the description of the igneous rocks of Arkansas. Dr. Williams secured leave of absence from Clark and entered on his Arkansas work as a volunteer without salary in October, 1889. In the summer of 1890 he was made honorary docent at Clark university. This title, like his previous one, carried no salary with it, and merely afforded him a work-room and headquarters. Dr. Williams gave some lectures on crystallography to chemists during one or two months in the spring, and for this purpose furnished his own models, diagrams, etc, and even loaned his own goniometer to the chemical department of the university for whatever measurements were made on crystallized salts.

Dr. Williams found a wealth of interesting material in Arkansas, and as the result of his collecting published in 1890 the papers on manganopectolite and eudialyte cited below. In the fall of 1890 he returned to Arkansas and completed his work, remaining, except for one or two trips home, until the summer of 1891. He had meantime accumulated the observations for his final and greatest work, which forms volume ii of the annual report of the Arkansas geological survey, and is entitled "Igneous Rocks of Arkansas." The volume, which is just distributed, contains 432 pages, 391 of which are by Dr. Williams alone, and which give an accurate and exhaustive petrographic description of the syenites, eleolite-syenites and leucite-syenites, the variations of all three, and the basic dikes which pierce them. Perhaps the greatest interest lies in the identification of leucite in these rocks and in the establishment of Cretaceous leucite-syenites as a new variety. This opposes the generally held but quite unwarranted belief that leucite is limited to the later volcanic rocks. The report is accompanied by beautifully executed topographic maps and by many other illustrations. Much of its success was made possible by the cordial and efficient support given Dr. Williams by Professor Branner, but it bears on every page the marks of tireless and painstaking scholarship. Professor Branner in the preface bears testimony to the enthusiasm and energy with which Dr. Williams carried it through, and the writer of this memorial, who was associated in some minor portions of the work, can witness also to his consuming interest in his work. Dr. Williams was appointed assistant geologist on the survey in 1891, and in this official capacity his name appears on the title page of the report. In 1891, in connection with Dr. R. N. Brackett, he carried on investigations in certain minerals of the Kaolin group, which appeared in the *American Journal of Science* in July last.

In June, 1891, the position of assistant professor of geology and mineralogy became vacant at Cornell university, and Dr. Williams was called to the chair. He accepted, and after making the western excursion of the International Geological Congress, he attempted to take up his duties, but weakness and disease were already laying a heavy grasp upon him. A severe attack of the so-called "grip" in March last had sapped his strength, and ill-advised methods of work had aggravated its results. Dr. Williams worked well but not wisely, and, led away by interest in his subject, protracted his labors until 2 and 3 o'clock in the morning. These habits are specially injurious in Arkansas, and gave his friends great anxiety. At last he became but the shadow of himself—the strain upon him was too severe and his constitution finally yielded. Paralysis attacked him, and after an illness of about two weeks he passed away on November 9, being just 29 years of age.

It has never been the lot of the writer to know intimately a more generous, frank and lovable man than J. Francis Williams, and it is impossible to speak of him without the deepest emotion. His character was such as to indescribably endear him to his friends, and his abilities and preparation for his work were of the highest order. His results were such as to secure for him in all the future one of the most honorable places in the records of American geological science.

A list of Dr. Williams' published papers is appended:

Tests of Rutland and Washington County Slates: *Van Nostrand's Engineering Magazine*, no. clxxxviii, 1884, pp. 101–103.

Ueber den Monte Amiata in Toscana und seine Gesteine: *Neues Jahrbuch*, Beilage Band v, 1887, Seiten 381–450 u. Tafeln xiii–xvi.

Manganopektolith, ein neues Pektolith-ähnliches Mineral von Magnet Cove, Arkansas: *Zeitschrift für Krystallographie*, B. xviii, 1890, S. 386.

Eudialyte and Eucolite from Magnet Cove, Arkansas: *Am. Journ. Sci.*, 3d series, vol. xl, 1890. pp. 457–462.

Tests of some Arkansas Syenites: *Railroad and Engineering Journal*, vol. lxv, 1891, p. 13.

Newtonite and Rectorite, two new Minerals of the Kaolinite Group (by R. N. Brackett and J. Francis Williams): *Am. Journ. Sci.*, 3d series, vol. xlii, 1891, pp. 11–21.

Annual Report Geological Survey of Arkansas, 1890, vol. ii: The Igneous Rocks of Arkansas, pp. 457, and maps.

J. F. K.

Mr. J. S. Diller, for the Committee on Photographs, made an oral report, stating that nearly three hundred new photographs were received since the last report and were on exhibition.

The reading of papers was declared in order, and the first paper on the printed program was announced, entitled—

THE MANNINGTON OIL FIELD AND THE HISTORY OF ITS DEVELOPMENT.

BY I. C. WHITE.

Remarks were offered by G. K. Gilbert, Arthur Winslow and E. W. Claypole. The paper forms pages 187–216, with plate 6 of this volume.

The second paper was—

FOSSIL PLANTS FROM THE WICHITA OR PERMIAN BEDS OF TEXAS.

BY I. C. WHITE.

In the subsequent discussion remarks in confirmation of the Permian age of the Wichita beds were made by several Fellows. Professor E. W. Claypole observed—

There is much to be said in favor of an American Permian, though there is considerable prejudice against the Permian on the part of some American geologists. I do not regard the finding of trilobites as an objection.

Professor Alpheus Hyatt said:

I have found the cephalopod fauna of the beds described by Professor White to be decidedly Permian.

In reply to a question, the author said the plant fossils of the American Permian were of fresh-water origin. Mr. E. T. Dumble remarked:

The plants sent to Professor White were taken principally from the Wichita beds, the lowest of the three divisions into which the Permian formation of Texas has been separated. The *Walchia*, however, is not confined to this division, but occurs also in the sandstone of the overlying Clear Fork beds. These plants occur in the beds in which are found the invertebrate forms described by Dr. C. A. White and which contain such characteristic Permian fossils as *Medlicottia*. These forms were examined by the Russian geologists at Washington during the meeting of the International Geological Congress, and were pronounced by them identical with the species found in the Permian of that country. The vertebrate forms described by Professor Cope as Permian were obtained also from the Wichita division.

The paper is printed on pages 217–218 of this volume.

A recess was voted until 2 o'clock.

On reassembling at 2 o'clock p. m. the following paper was read:

GEOLOGY OF THE TAYLORVILLE REGION OF CALIFORNIA: PART I—THE GEOLOGIC COLUMN.

BY J. S. DILLER.

This was immediately followed by—

JURA AND TRIAS AT TAYLORVILLE, CALIFORNIA.

BY ALPHEUS HYATT.

The two papers were discussed by E. W. Claypole, W. H. Pettee, I. C. White and G. K. Gilbert.

The next paper was a continuation of one of the preceding:

GEOLOGY OF THE TAYLORVILLE REGION OF CALIFORNIA: PART II—STRUCTURE.

BY J. S. DILLER.

The three papers are printed as pages 369–412 of this volume.

In the absence of the author, the following paper was read in abstract by C. Willard Hayes:

STRATIGRAPHY AND SUCCESSION OF THE ROCKS OF THE SIERRA NEVADA OF CALIFORNIA.

BY JAMES E. MILLS.

This communication was discussed by G. K. Gilbert, C. W. Hayes and J. S. Diller. It forms pages 413–444, with plate 13 of this volume.

The following paper was read by J. S. Diller, the author not being present:

SECONDARY BANDING IN GNEISS.*

BY WM. H. HOBBS.

The fact that secondary cleavage or foliation is to be found in the schistose rocks of Berkshire county, Massachusetts, is mentioned by Dana in his papers on the geology of the region. The extent to which it is developed and the importance of carefully distinguishing it from planes of stratification in the working out of geologic structure was first emphasized in the study of the Greylock group by the

*Published by permission of the Director of the United States Geological Survey.

SECONDARY BANDING IN GNEISS.

Archean division of the United States Geological Survey, in charge of Professor Raphael Pumpelly. Mr. T. Nelson Dale, assistant geologist, has prepared a monograph on mount Greylock, in connection with which he has made an extensive study of secondary foliation.* A summary of his conclusions is contained in the *American Geologist* for July, 1891.†

The rock exposure illustrating the peculiar structural feature which forms the subject of this paper is located east of the village of Great Barrington, near the Hopkins-Searles dolomite quarry. The locality has already received considerable attention from geologists. Professor Dana, in his first series of papers on the geology of Berkshire county,‡ printed a section passing through the locality, at which the apparent unconformity of the limestone and gneiss was explained by a fault. The portion of the section in question was printed on a larger scale as "section number 25" of his paper on Taconic rocks and stratigraphy.§ This is reproduced in figure 1.

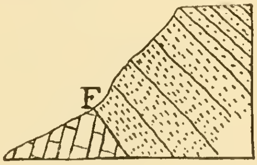


FIGURE 1.—*Section near Great Barrington (after Dana).*

Julien, in a paper entitled "On the Geology at Great Barrington, Massachusetts,"‖ has described the same locality. His views of the geologic structure are expressed in figure 2.

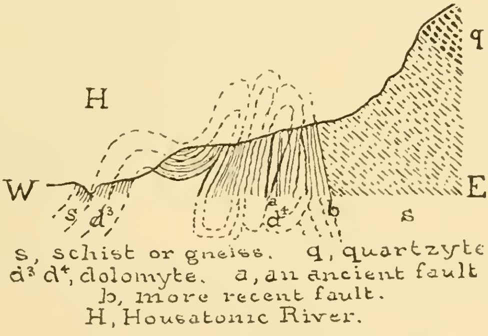


FIGURE 2.—*Section near Great Barrington (after Julien).*

Mr. T. Nelson Dale,¶ assistant geologist in the Archean division of the United States Geological Survey, visited the Searles-Hopkins quarry at Great Barrington on October 5 and 14, 1889, and Mr. J. E. Wolff examined the gneiss later microscop-

* Now in the hands of the public printer at Washington.

† The Greylock Synclinorium: Am. Geol., vol. viii, pp. 1–7.

‡ On the Quartzite, Limestone and Associated Rocks of the vicinity of Great Barrington, Berkshire county, Mass.: Am. Journ. Sci., 3d series, vol. v, 1873, p. 26, fig. 7.

§ On Taconic Rocks and Stratigraphy, with a Geological Map of the Taconic Region: Am. Journ. Sci., 3d series, vol. xxxiii, 1887, p. 400, with plate 11.

‖ Trans. New York Acad. Sci., vol. v, 1887, p. 28.

¶ This paragraph and the accompanying figure 3 were prepared for this paper by Mr. Dale.

ically. In Mr. Dale's report to Professor Raphael Pumpelly, United States geologist, dated March, 1890, he described the locality in the following words:

"East of Great Barrington, at the Searles-Hopkins quarry, a rather coarse-grained muscovite biotite gneiss is in contact with a micaceous pyritiferous dolomite. An analysis of the dolomite is given by Mr. A. A. Julien in his paper on the geology of Great Barrington (*Transactions of the New York Academy of Science*, vol. v, 1887, page 37). The plicated stratification planes of the gneiss dip at the contact 30°–40° west, and westerly dips occur also along the steep part of the base of mount Keith, both north and south of the quarry, but the gneiss on the hill due south of the reservoir has a stratification dip only a few degrees east or west of 90°. The cleavage-foliation dip at the quarry is, however, 60° east. The relations of the stratification-foliation to the cleavage-foliation are shown in the accompanying sketch, made from a specimen. The general relations of stratification and cleavage in the schists of Berkshire county were set forth in my report on the areal and structural geology of mount Greylock."

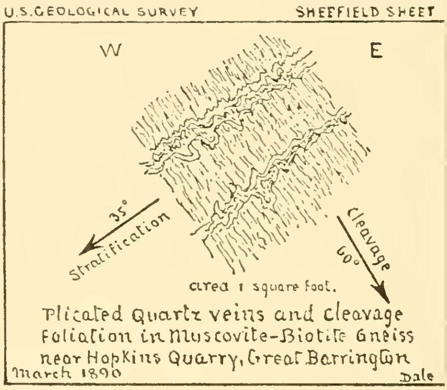


FIGURE 3.—*Cleavage and Bedding near Great Barrington (after Dale).*

The Hopkins-Searles quarry lies very near the line separating the portions of territory allotted to Mr. Dale and myself for study. Ignorant of the fact that he had examined the locality, I visited it in July, 1890, and arrived at the same conclusions concerning the general structural relations that he had reached in the previous season. Figure 4 shows the probable relations at the quarry.*

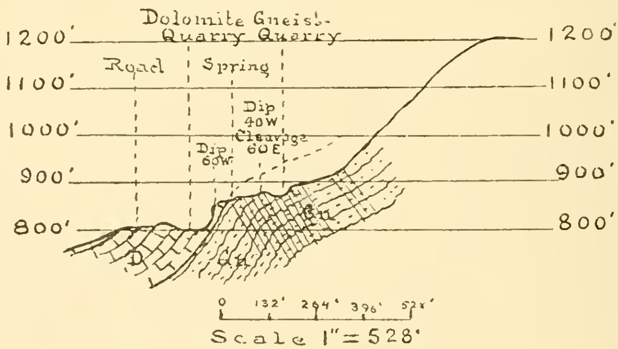


FIGURE 4.—*Structure of Hopkins-Searles Quarry.*

* A uniformly easterly cleavage-foliation exists also in the schist west of the Great Barrington valley, where it corresponds more or less closely in direction with the bedding plane.

The gneiss is mainly composed of quartz, feldspar and mica, and effervesces slightly with acid. Thin sections show that it contains rather more muscovite than biotite, and, as accessory minerals, zircon and magnetite. The dip of the dolomite in the southern part of the quarry is 60°–70° west, and the strike about north 15° west. Corresponding dips occur in the northern quarry. In ascending the hill the gneiss is first met with at the spring (about 50 feet from the upper edge of the quarry). Besides a cleavage-foliation (60°–70° east), the gneiss shows a marked *straight banding*, the direction of which is the same as the foliation. No other structure than these two was discovered. A few paces above the spring an opening has been made in the gneiss by a small quarry, and a similar opening has been made about 100 feet farther northward. Here the mass of the rock is fresher and shows the same structure as that at the spring, with the exception that much contorted lenses of quartz clearly show the position of an earlier structure-plane, which now has an average dip of 40° west, with steeper dips on the west and lower dips on the east. Locally other evidences of this structure can be made out, namely, a *crumpled banding* having the same direction as the contorted quartz lenses. On the northern wall of the more northerly of the two quarries this structure is brought out in great perfection.* The strike of the cleavage-foliation at this locality is north 15° west; the bedding-plane appears to strike about north 9° west. With the assistance of a skilled stone-worker, a block of gneiss was cut from this spot so as to have its face approximately perpendicular to the strike. The dimensions of the face of the block were about two feet by one and its thickness about a foot. This block has been sawed twice through parallel to its face and the plane surfaces of the slabs carefully smoothed. One surface of the middle slab also has been given a polish. A photograph of this surface is reproduced in plate 14.

The unique feature of this specimen does not consist in the crumpled bands, the contorted quartz lenses, or the cleavage foliation, all these having been observed in other localities in Berkshire county,† though it is doubtful if the three structures have been observed together in such perfection as at this locality. The novel feature is the secondary straight banding parallel to the induced foliation. This banding is due to an alternation of layers of different mineral composition, which gives the structure an appearance very like that of ordinary sedimentation. The white bands are composed mainly of quartz and feldspar, the dark ones of mica. These bands no doubt date from the same period and were produced by the action of the same forces as the foliation. As already stated, the straight banding and foliation are the prevailing structures at the locality, the crumpled banding being observed only at a few localities; and it is noticeable that at these localities the straight banding dies out altogether as it meets the series of crumpled bands, to recur again on the other side of them, as indicated in plate 14.

The occurrence of parallel layers of different mineralogical composition in a metamorphosed clastic rock has been considered one of the best criteria in determining the planes of stratification, where these have been partially effaced by subsequently induced structures. The structures observed in the gneiss of the Hopkins-Searles quarry indicate that one may easily be deceived in applying this principle.

EXPLANATION OF PLATE 14.

The plate shows a polished slab of calcareous muscovite biotite gneiss from near the Hopkins-Searles dolomite quarry at Great Barrington, Massachusetts. The size of the face is about 2 feet by

* It is also well marked a little way north of the quarry in a low ledge, and can also be seen, though in less perfection, in blocks now to be found in the southern quarry.

† See Dale, op. cit.

1 foot. A well developed cleavage-foliation runs parallel to the side on which the block rests. In *AA* and *A'A'* a nearly straight secondary banding follows this direction. At *BB* this banding is completely replaced by a crumpled transverse banding, showing the present position of the original stratification plane. At *CC* the course of a crumpled quartz lens can be followed parallel to that of the crumpled banding.

In discussing the paper Dr. J. E. Wolff remarked—

There is a similar example on a large scale in the metamorphic conglomerate series at East Clarendon, near Rutland, Vermont. The rock has a vertical banding and foliation, and the bands, being of different mineral composition, might be taken for stratification, were there not present occasional bands of pebbles with an undulating horizontal course which indicate the original stratification, while the individual pebbles have their major axes turned so as to lie in the plane of vertical banding and are somewhat stretched in that plane.

The next paper was read by Professor C. W. Hall:

PALEOZOIC FORMATIONS OF SOUTHEASTERN MINNESOTA.

BY C. W. HALL AND F. W. SARDESON.

In discussing the paper W J McGee remarked—

There is some confusion in the nomenclature of the series of upper Cambrian and basal Silurian strata so admirably described by the authors of this communication. While there are local and inconstant unconformities, the series as a whole is a continuous one connecting the Cambrian and Silurian. This series is relatively complex in Minnesota and still more complex in Wisconsin, but relatively simple in Iowa; and in the areas of complex structure, divisions have been discriminated that are lost in the areas of simple structure. Moreover, Owen's name "Lower Magnesian" has become misleading since his correlative term "Upper Magnesian" (including the Niagara and Galena and by implication the intervening Maquoketa) has been dropped from geologic language and literature. Partly for these reasons, the Iowa representative of Owen's "Lower Magnesian," which corresponds to Irving's "Main Body of Limestone," has been called Oneota limestone from the river on which the formation is typically developed.*

Professor Hall replied:

While a certain degree of confusion attaches to the use of Owen's term "Lower Magnesian" for the rocks in question, that confusion disappears when the first element in the name is dropped. "Magnesian" is at the same time a convenient name and possesses the advantages of accurately describing the lithologic and chemical characters of the great mass of dolomite to which it is applied, and of closely corresponding to the original designation which has taken an established place in geologic literature. Indeed the word has become so well fixed in the northwest that we can use it with ease, notwithstanding the advances already made in our knowledge of the rocks included under it. It is the intention of the authors to continue their studies of these strata, discussed in barest outline in the

*11th Ann. Rep. U. S. Geological Survey, 1892, p. 332.

paper presented, and to discover everything they can touching their lithologic and paleontologic characters. The interesting results which have already attended their explorations of the Saint Peter sandstone give great encouragement that something of interest will be developed by a careful and systematic study of the rocks underlying that horizon. When their paleontologic investigations shall be well advanced it may be that a name of some real paleontologic significance can be attached to these rocks in place of the lithologic one now in such universal use. Certainly the retention for the present of the old name cannot add any confusion to nomenclature. The position taken by Mr. McGee is appreciated, and the name proposed by him in Iowa, Oneota limestone, may yet prove to be the best one to adopt for Minnesota and Wisconsin.

The paper with its illustrations is published as pages 331–368, with plates 10–12 of this volume.

After announcements from the Chair concerning the evening session the Society adjourned.

Evening Session of Tuesday, December 29.

The Society was called to order at 7.30 p. m. and a lecture was delivered on—

MOUNT ST. ELIAS AND ITS GLACIERS.

BY ISRAEL C. RUSSELL.

The lecture was illustrated by maps and lantern views. Remarks were made in discussion of the subject by G. F. Wright, G. K. Gilbert and others.

Following the lecture by Mr. Russell, Dr. J. E. Wolff exhibited and described a series of lantern views illustrating a paper on the Crazy mountains, to be read at a later session.

The President made announcements and the Society adjourned. After adjournment an informal reception was given the Society and the Ohio State College Association by the local Reception Committee. Brief addresses were made by Rev. Dr. Bashford, Mr. Gilbert and Professor Kellicott.

SESSION OF WEDNESDAY, DECEMBER 30.

The Society was called to order at 10 o'clock a. m. by President Gilbert.

The Council report, deferred from the preceding day, was declared in order and was read by the Secretary as follows:

REPORT OF THE COUNCIL.

To the Fellows of the Geological Society of America.
in Fourth Annual Meeting, 1891:

The Council congratulates the Society on the prosperity and success of its third year. The record is one of growth, prosperity and achievement. The Society has now drawn into itself, speaking not too broadly, the geologists of the continent, and a fine spirit of loyalty and of good-fellowship has been shown among its members. As the only geological association in America, and perhaps the only society in existence restricted to working geologists, every Fellow should feel a just pride and a personal responsibility in the success of the Society.

Meetings of the Council.—Since the last report was made the Council has held four meetings; two of them with two sessions. One was held at the close of the winter meeting, one in April, one preceding, and one during the summer meeting; all of them being in Washington. The attendance was large, and an earnest effort has been made to promote the interests of the Society.

Meetings of the Society.—The records of the two meetings held since the last report will be found in the printed proceedings. At the winter meeting the registered attendance was sixty-six, and at the summer meeting eighty-three. Considering the great area over which the membership is distributed it is a matter of congratulation that the attendance has been so large, as indicating the vigor of the Society and the interest of the Fellows.

Membership.—During the past year the Society has suffered loss by the death of President Winchell and of J. Francis Williams and by one resignation. At the summer meeting thirteen men were elected. The roll now includes the names of two hundred and thirteen Fellows, to which should be added the names of the two Fellows declared elected at this meeting.

Five Fellows are so in arrears for dues that unless payment is made before January their names must be erased from the roll under the rules (By-Laws, chap. 1, sec. 3).

The Council will soon nominate for Correspondents several eminent

foreign geologists. Their election will involve the presentation of as many copies of the Bulletin.

Bulletin Publication.—The first part of volume 3, the proceedings of the summer meeting, will soon be ready for distribution, having been delayed by unusual circumstances. It has been decided to limit the volume to five hundred pages.

The "Rules Relating to Publication," which were mailed to the Fellows previous to the summer meeting, formulate the legislation of the Society and Council upon the whole matter of the Bulletin and embody the teaching of experience up to this time.

Bulletin Distribution.—The brochures of volumes 1 and 2 were distributed to the Fellows directly from Washington with many losses. These deficiencies have been made good to the Fellows as far as known, being supplied from the reserve stock. Henceforth the entire distribution of the Bulletin will be from the Secretary's office, and care will be taken to distribute promptly and without loss.

The disposition of the surplus stock of volumes 1 and 2 is shown in the following table:

Bulletin Distribution from the Secretary's Office January, 1891, to January, 1892.

BY COMPLETE VOLUMES.

	Vol. 1.	Vol. 2.
Held in reserve	138	393
Donated to institutions ("exchanges")	73	73
Held for "exchanges"	19	19
Sent to Fellows to supply deficiencies	2	1
Sold to Fellows	7	5
Sold to Libraries	21	21
Donated by direction of Council	3	3
Bound for office use	1	1
Number of complete copies received	264	516

BY BROCHURES.

		Vol. 1.	Vol. 2.
Sent to Fellows to supply deficiencies	(to 4 Fellows)	33	
	(to 17 Fellows)		63
Sold to Fellows		5	2
Sold to non-Fellows	(to 1 person)	1	
	(to 8 persons)		15
Total		39	80

There remains a considerable stock of extra brochures which cannot be collated into volumes.

Bulletin Sales.—It was not deemed advisable to advertise the Bulletin until its character and permanence were established. The condition has

now been reached where it is proper and feasible to seek some income from the publication. The Fellows are again requested to use their influence toward the sale of the Bulletin to libraries by permanent subscription. Through the recent efforts of the Fellows, twenty-five libraries have subscribed.

The sale of the Bulletin to date is itemized in the preceding and the following tables:

Receipts from Sale of Bulletin, January, 1891, to January, 1892.

BY SALE OF COMPLETE VOLUMES.

	Vol. 1.	Vol. 2.	Total.	
From Fellows	$35 10	$22 50	$57 60	
From libraries	80 00	80 00	160 00	
Total	$115 10	$102 50		$217 60

BY SALE OF BROCHURES.

	Vol. 1.	Vol. 2.	Total.	
From Fellows	$2 75		$2 75	
From non-Fellows	40	$4 95	5 35	
Total	$3 15	$4 95		$8 10

Total receipts	$225 70
Due and not collected for five sets and two brochures	50 45
Grand total from sales	$276 15

There has been paid in advance for volume 3 the sum of $15.

Bulletin Donations (" *Exchanges* ").—At the beginning of the year a small list had been made of societies and institutions to which it was proposed to donate the Bulletin, authority having been given the Council at the New York meeting. This list was afterward extended and a circular letter was sent to the addresses. The two volumes have been sent to all the addresses which responded to that letter, sixty-eight in all, distributed as follows: United States, 12; British America, 5; South America, 1; Great Britain and Ireland, 7; Europe, 32; Asia, 3; Australasia, 6; Hawaiian islands, 1; Africa, 1. To five other addresses the volumes have been sent in anticipation of replies to the letter. In this matter the desire of the Council has been to place the Bulletin where it will be the most useful, rather than to seek a return in kind.

Exchange Product (Library).—It is certain that many institutions receiving the Bulletin will desire and expect to send their publications in return, and the Society is sure to be the recipient of much printed matter from many sources. Some material has already been received, in addition to the photographs, manuscripts, books, etc. collected by Professor

Hitchcock with permission of the Council. With no home or permanent location for the Society, the proper disposition of library material has been a problem. The result of the consideration of this question is a prevailing sentiment in favor of depositing the Society's library in some institution where it may be useful to the Fellows of the Society who are far removed from the great libraries of the eastern states. By authority of the Council the Secretary has held correspondence with several colleges and libraries with the result that offers are now before us to receive the material on deposit under conditions which relieve the Society from all expense, even for binding, while retaining full ownership.

Finances.—The available income of the Society is limited to the annual dues and the inconsiderable interest from an investment of less than $1,200. This is barely sufficient to pay the cost of economical administration and of a volume not expensively illustrated.

The cost of volumes 1 and 2 is shown in the following tabulation:

COST OF BULLETIN.

Cost to the Society:	Vol. 1. (pp. 593; pl. 13.)		Vol. 2. (pp. 662; pl. 23.)	
Letterpress	$1,367 77		$1,935 27	
Illustrations	291 85		302 35	
Total		$1,659 62		$2,237 62
Cost to Authors:				
Illustrations			$161 30	
Corrections	$38 00		27 25	
Brochure covers	68 00		30 00	
Total		$106 00		$218 55
Aggregate		$1,765 62		$2,456 17

Fellows are urgently requested to assist in increasing the Society's income and to establish a publication fund. The securing of subscriptions to the Bulletin is a reliable help, even if not large. The Council desires to repeat the demand for $10,000 as a fund for publication.

Recommendations.—The Council makes the following recommendations:

1. That the Council be authorized to increase the list of "exchanges," if deemed desirable, to a number not to exceed one hundred.

2. That the Council be authorized to deposit the library material acquired by the Society in some institution, under terms which shall leave the Society in absolute ownership.

3. That in recognition of his services to the Society Dr. J. J. Stevenson be elected a Life Member, with dues remitted.

The report of the Council was received, and the three recommendations were adopted by formal vote.

The proposed amendment to the By-Laws was taken from the table. During debate, remarks were made by several Fellows. An amendment to the amendment was offered by Professor Pettee, which was adopted; and the amendment, to read as follows, was adopted unanimously:

"Chapter ii. Article 7: The Council may transact its business by correspondence during the intervals between its stated meetings; but affirmative action of a majority of the Council shall be necessary in order to make action by correspondence valid."

The Auditing Committee reported the accounts of the Treasurer correct. The report was adopted.

The Committee on Photographs made a formal report, which was adopted. It was voted that the committee be continued, and the unexpended balance of the appropriation be available for the coming year. The report is as follows:

SECOND ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS.

The total number of photographs now in the collection of the Geological Society is 635. Last year the collection reached 293. This year 342 photographs have been added to the collection by the donors whose names appear in the register. When duplicate photographs are desired, application should in all cases be made directly to the individual who presented the photographs to the Society.

Some of these views, together with those collected last year, were exhibited in Washington at the summer meeting of the Geological Society and at the American session of the International Geological Congress. All of the views received this year, excepting those presented by the Geological Survey of Canada, were exhibited at the Columbus meeting.

The collection is now at the office of the United States Geological Survey in Washington, D. C., in charge of the Washington member of the committee, where it is readily accessible to Fellows for examination.

The expenses of the committee during the year in collecting the photographs, temporarily binding them, and preparing them for exhibition, were $9.83.

The committee solicit the donation of good photographs which clearly illustrate important geologic phenomena. They may be sent to any member of the committee at the following addresses: Professor J. F. Kemp, Columbia College, New York city; Professor W. M. Davis, Harvard College, Cambridge, Mass.; Mr. J. S. Diller, U. S. Geological Survey, Washington, D. C.

Prints smaller than 4 x 4¼ inches are not desired. All prints should be mounted; and for artistic effect, as well as ease of preservation, gray cards are preferred.

Each photograph should be plainly labeled, either on card or plate, giving the subject, with a brief but explicit reference to what is illustrated by the photograph, its date, locality, name of the artist and donor, and a reference to its publication, if the photograph has been published. The label should be placed, if in type, on the front beneath the photograph; if in script, on the back.

The photographs should be accompanied by a statement whether duplicates and lantern-slides can be obtained, and at what price, and the address of the person to whom application for them should be made. It is suggested that in order to save trouble to donor, arrangements be made with local photographers to whom the negatives may be entrusted to fill orders.

Initials in parentheses at the end of labels indicates authorship within the committee.

Register of Photographs received in 1891.

Photographed and Presented by Dr. G. H. Williams, of Johns Hopkins University, Baltimore, Md.

Size, about $4\frac{1}{2}$ x $6\frac{1}{2}$ inches. Photographs of laboratory specimens.

294. Appalachian structure: anticlinal fold running into a synclinal; Cumberland, Md.
295. Anticlinal fold; Animikee slate, Pigeon point, lake Superior.
296. Folded Halla-flinta; Naerodal, Norway.
297. Gneiss; Stony Point-on-the-Hudson, N. Y.
298. Slate, showing bedding, cleavage and rigid calcareous layer; Bangor, Pa.
299. Quartz-schist, with stretched tourmaline; Shoemaker's quarry, Green Spring valley, Baltimore co., Md.
300. Dike of red granite in green hornblendite; Pigeon island, near Marquette, Mich.

Photographed and Presented by G. P. Merrill, of the United States National Museum, Washington, D. C.

Sizes, 4 x 5 and 8 x 10 inches.

301. Slate, showing cleavage and faulting (compare 298); Bangor, Pa.
302. Gneiss, showing foliation (natural size); from blocks in the building-stone collections of the United States National Museum; Lawrence and West Andover, Mass.
303. Pyroxenite nodules, partially altered into serpentine; Montville, N. J. (3 nodules on one plate, published in Proc. U. S. Nat. Museum, vol. xi, 1888, p. 112, pl. xxxi).
304. Quarry in Triassic sandstone; Portland, Conn. The view shows the varying thicknesses of the beds and their nearly horizontal arrangement.
305. Fold in slate quarry; Bangor, Northampton co., Pa. The slaty cleavage extends from the left slightly downward to the right and directly across the apex of the fold.
306. The Franklin slate quarry; Slatington, Lehigh co., Pa. The view shows the slaty cleavage cutting across the bedding at a high angle, the quarry opening being near the apex of a fold.
307. Slate quarry; Bangor, Pa. In the distant right, at the foot of the derrick, a fold in the slate is shown somewhat indistinctly.
308. Marble quarry; West Rutland, Vt. View looking downward from the surface and showing the inclined position of the beds. (This view forms plate i of the Handbook of the Collection of Building and Ornamental Stones in the United States National Museum, Smithsonian Report, 1885–'86, part ii).
309. Granite quarry; Hallowell, Maine. This view shows the lenticular character of the sheets and their imbricated arrangement. Nearly vertical joint-faces are shown at the right. (This view forms plate viii in the Handbook named above.)

Photographed and Presented by Professor P. H. Mell, Auburn, Ala.

Views of the Tallulah falls region of Rabun co., Ga. Size, $4\frac{1}{2}$ x $7\frac{1}{2}$ inches.

310. Lodore fall.
311. Rapids in Grand chasm.
312. Rapids at head of Hurricane fall.
313. Cairis head.
314. Hickorynut mountain.
315. Glenella spring.
316. Group of Indians.
317. Sweet Sixteen falls.
318. Sinking mountain.

Photographed and Presented by Professor H. L. Fairchild, Rochester, N. Y.

Views of the vicinity of Rochester, N. Y. Size, $6\frac{1}{2}$ x $8\frac{1}{2}$ inches.

319. *Pentamerus*, or lower Clinton limestone, with the Clinton iron ore; ravine of the Genesee.
320. Another view of subject of 319.
321. Niagara formation; lower falls of the Genesee and the Seneca park bridge; near view.
322. The same; distant view.
323. Section of a glacial drift hill (kame); Cobb's hill, Monroe ave.
324. Another section of the kame; same subject as 323.
325. Another section of the kame; same subject as 323.

Photographed and Presented by the Geological Survey of Texas; E. T. Dumble, State Geologist, Austin, Texas.

Size, 6 x 8 inches.

326. Kountz series: Contact of volcanic ash and chalk.
327. " " Flints on hill.
328. Pilot Knob series: View under bluff of great anticline; decomposition of tuff and stalagmites.
329. Pilot Knob series: Bored limestone above tufa.
330. Mount Bonnell series: Under the cliff.
331. " " " Colorado river from western side of mount Bonnell.
332. Blue Bluff series: Characteristic *Ponderosa* marl section.
333. " " " " " " (continuation of 332).
334. McDonald Quarry series: Flagstone beds.
335. Bee Spring series: Fault in limestone.
336. Barton Creek series: Fault in limestone.
337. Travis Peak series: Trinity beds.
338. " " " Rain erosion.
339. " " " Characteristic topography.
340. " " " Trinity and Fredericksburg topography.
341. Sandy Gap: Cambrian cliffs.

342. Shoal Creek shell bank: *Exogyra arietina*, Roem.
343. Cataracts; Honey creek, Llano co.
344. Walsh's quarry near Austin: Limestone and flint.
345. Flint nodules in chalk; southern bank of Colorado river.
346. Lower Cambrian conglomerate; Burnet co.
347. Colorado valley with "Niggerhead" in distance; from Hoover valley, Burnet co.
348. "Niggerhead" mountain, Burnet co.
349. Deep Eddy; bank of Colorado river between Bee spring and Fisherman's hut, near Austin.
350. Potsdam and Silurian contact; Morgan creek, Burnet co.

Photographed and Presented (in an album) by Robert Hay, P. O. Box 562, Junction City, Kansas.

Size, Kodak circular, $3\frac{5}{8}$ inches diameter.

351. Bear Butte; South Dakota. From the south.
352. " " " " Needle rocks, on eastern end.
353. " " " " From southwest, showing rhyolite and Dakota sandstone.
354–360. Sandstone dikes in White river Bad-lands; near Chadron, northwestern Nebraska. 354, 355, 358 and 360 show dike no. 1; 356, 357 and 359 show dike no. 2.
361. Moraine bowlders showing through the snow; south of Edgarton, S. D.
362. Drift bowlders in James river bluff; near Jamestown, N. D.
363. Glacial bowlder gravel or glacial clay; Jamestown, N. D.
364. Alkaline lake and mud flat; Coteau du Missouri, N. D.
365. Lake in the Coteau; N. D.
366. Alkaline lake with bowlder beach in the Coteau du Missouri; Northern Pacific ry., N. D.
367. Lake in the Coteau; near Crystal springs, N. D.
368. Lakes in the Coteau du Missouri; N. D.
369. The Coteau du Missouri; southeast of Crystal springs, N. P. ry., N. D.
370. " " " " south " " " " "
371. " " " " southwest " " " "
372. " " " " " " " " "
373. " " " " N. D.
374. " " " " "
375. Summit of the Coteau; N. D.
376. Outcrop of Tertiary grit; Scott co., Kas.
377. Rainbow falls of the Missouri; Montana.
378. Yellow chalk surmounted by Tertiary grit; Norton, Kas.
379–385. Seven views of the "Crest of the Apishapa," a trap dike on the plains between Trinidad and Pueblo, Col. The dike rises 500 feet above the level of Apishapa creek. Its northern front is in parts 150 feet vertically. 379 is a view from the west, 380 from the southeast, and 381 from the top looking eastward; 382 shows the top, 383 is a view from the top, and 384 is a near view of the southern side, 385 being also a view from the south.

Presented by Dr. W. H. Hobbs, State University, Madison, Wis.

Size, $4\frac{1}{2}$ x $7\frac{3}{4}$ inches.

386. Warner mountain; from Great Barrington, Mass. Searles quarry on the left.

387. Contact of Cambrian (Silurian) gneiss overlying dolomite; above Searles quarry, Great Barrington, Mass. Looking southwest; mount Washington in the distance. The exposures on the left are gneiss, those on the right, either side of derrick, are dolomite. The exposure where crumpled banding in gneiss is best exhibited is seen in the left middle ground.

388. Crumpled banding in gneiss; near Searles quarry, north of most northerly opening.

389. Polished slab of calcareous muscovite-biotite gneiss; from above the Hopkins-Searles dolomite quarry at Great Barrington, Mass. The size of the face is about 1 x 2 feet. A well developed cleavage foliation runs parallel to the side on which the block rests. A nearly straight secondary banding follows this direction. This banding is completely replaced by a crumpled transverse banding showing the present position of the original stratification plane. The course of the crumpled quartz lenses can be followed parallel to that of the crumpled banding (published as plate 14 of this volume).

390. Quarry in Cambrian gneiss; above Searles quarry, Great Barrington, Mass. Shows perfect foliation and straight lamination, dipping toward the right, and in the lower right-hand corner the straight lamination is replaced by a crumpled banding which is parallel to the two series of quartz lenses and dips westward 40°–60°, conformably with overlying dolomite 100 feet westward. The polished specimen (no. 389) was separated from this exposure in the lower right-hand corner of the view at *A*.

391. Polished specimen of gneiss; from near Searles quarry, Great Barrington, Mass. Showing crumpled quartz lenses across lamination and foliation. One-half natural size.

Photographed and Presented by S. R. Stoddard, Photographer, Glens Falls, N. Y.

Nos. 392 to 414, size 7 x 9 inches, price (post-paid) 50 cents each; nos. 414 to 454, size 5 x 8 inches, price (post-paid) 30 cents each. (Mr. Stoddard's numbers are given in parentheses for the convenience of those who may wish to order views.)

392 (66). Clear lake; from mount Jo, Adirondacks. The forest cover of our northern mountains is beautifully illustrated in this view. The next photograph (393) illustrates the devastation produced by forest-clearing (W. M. D.).

393 (494). The trail of the charcoal-burner; Adirondacks.

394 (486). Lower Ausable lake; Adirondacks. An excellent illustration of a preglacial valley obstructed by a drift barrier and thus forming a linear lake (W. M. D.).

395 (489). Upper Ausable lake: Haystack mountain; from inlet.

396 (488). " " " "The Gothics;" from inlet.

397 (13). Ausable chasm: Column rocks; a post-glacial gorge cut in Potsdam sandstone. This is a good type of the many gorges of New York, all of which may be classed as the product of streams turned across old rocky slopes by drift barriers which now occupy the former valleys (W. M. D.).

398. Ausable chasm: Rainbow falls.

399 (19). " " Grand flume; from rapids down.

400 (17). " " View upward from Table rock.

401 (492). The White mountains and the Ammonoosuc river.

402 (131). West Point; looking northward from the plain.

403 (60). Charcoal kilns on the Chateaugay railroad.

404 (543). Glens Falls, Hudson river. The great volume of the Hudson river below Albany is not due to a rainfall supply gathered from a large basin, but to the drowning of the river by a slight depression of its valley below sea level. The view at Glens Falls shows the river in its proper dimensions. It has here cut down through a drift cover by which it has been diverted from its ancient pre-glacial course, and at Glens Falls has been locally superimposed on a series of horizontal strata, in which it has cut a rocky gorge and at the head of which it descends in picturesque falls (W. M. D.).

405 (804). Lake George: Panorama from Pearl point to Black mountain.

406. Lower falls: Falls creek gorge; Ithaca, N. Y.

407 (79). Lake Placid and Mirror lake; from Grand View house.

408 (436). Indian pass; Adirondacks.

409 (574). Western panorama from hotel Champlain; Lion mountain.

410 (556). Lake Champlain: Looking northeastward from Westport.

411 (560). The palisades of lake Champlain.

412 (559). Barn rock; lake Champlain.

413 (521). Howes cave, N. Y.; "Alabaster hall."

414 (515). " " " "The Eagle's wing."

415 (48). Keene valley, N. Y.; Adirondacks. Characteristic view of lowland of glacial gravels with which the bottoms of our northern valleys are often so deeply clogged (W. M. D.).

416 (20). Keene valley, N. Y.; looking southward from Brook Knoll lodge.

417 (43). " " " Tahawus house.

418 (23). " " " Beede house.

419 (75). Ray brook; Adirondacks. A typical meandering stream in a marshy flood-plain (W. M. D.).

420 (707). Blue Mountain lake; Adirondacks. Very expressive view of the smaller Adirondack lakes, whose origin is to be ascribed chiefly to obstruction by drift of broad pre-glacial valleys in a rugged, rocky country (W. M. D.).

421 (715). Blue Mountain lake; from Merwins.

422 (404). Ausable chasm; Adirondacks. A post-glacial gorge cut in Potsdam sandstone. This is a good type of the many gorges of New York, all of which may be classed as the product of streams turned across old rocky divides by drift barriers now occupying their former valleys (W. M. D.).

423 (34). Upper Ausable lake; from Boreas bay.

424 (72). View from St. Regis mountain; Adirondacks. A good bird's-eye view of the lacustrine topography of a rocky drift-covered region.

425 (559). Bog river falls; Adirondacks. These falls, like all those of our northern states, result from the displacement of streams from their pre-glacial valleys by drift obstructions which turned them over old rocky divides. This view is taken where Bog river enters Tupper lake. The next view (426) shows the quiet upper course of the same stream where it flows over a drift surface not yet trenched on account of the rock barrier at the falls (W. M. D.).

426. Bog river; near Tupper lake.

427 (501). Whiteface mountain summit.

428 (1096). Stony creek; near Spectacle ponds. Typical form of meandering stream in floodplain among the mountains.

429 (1057). Trap dike; Avalanche lake. Massive mountains of foliated gneiss, intersected by a dike that has weathered out, leaving a chasm (W. M. D.).

430 (1055). Avalanche lake; Adirondacks. A pre-glacial rock-walled valley, obstructed by glacial drift (W. M. D.).

431 (1204). Woods Holl, Mass. A low rocky and drift-covered headland between Buzzards bay and Vineyard sound. The terminal moraine has strong development in this neighborhood. The tidal currents between the islands hereabouts are very strong (W. M. D.).

432 (1207). Monomoy point; looking northward from Monomoy lighthouse, cape Cod, Mass. Monomoy is a long sand-bar formed by the conflict of wind and tidal currents south of the elbow of cape Cod. Its surface is at present covered by shifting sand-dunes with very sparse vegetation (W. M. D.).

433 (1206). The Powder hole: Monomoy lighthouse; from the lighthouse.

434 (1244). Mount Desert island; from Green mountain. Mount Desert contains the highest land on the Atlantic coast of the United States. Its east and west mountain range marks the location of a great granite intrusion in ancient crystalline and Paleozoic (?) rocks; the present height of the range above the adjacent surface being due to the superior resistance of its rocks to denudation and not to upheaval. The range is now deeply dissected by transverse valleys, and these are deepened by glacial action. The fjord-like quality of the coast and the outlying islands indicate a submergence of the region since the valley system attained its present form (W. M. D.).

435 (1246). Mount Desert island; looking southwestward from Green mountain.

436. Eagle lake, Mount Desert island; looking northwestward. Eagle lake lies in one of the transverse valleys by which the granitic range of mount Desert is deeply dissected. In the distance the narrow arm of the sea by which the island is separated from the mainland may be seen (W. M. D.).

437 (1241). Mount Desert island: Bar Harbor; looking southwestward from Green mountain.

438 (1245). Mount Desert island: Bar Harbor; looking southwestward from Green mountain.

439 (1228). Mount Desert island: Bass Harbor lighthouse.

440 (1375). Entrance to harbor of Saint John, N. B.; looking inland. This harbor is entered through a narrow gateway of rock in which the tidal currents or "falls" are very rapid. This view shows the "falls" at ebb tide (W. M. D.).

441 (1374). Locality same as 440; "falls" at flood tide.

442 (1398). Low tide in the basin of Minas; Nova Scotia. Excellent illustrations of mud flats and tide-water gullies on the slopes (W. M. D.).

443 (1399). Low tide in the basin of Minas; N. S.

444 (1311). Hudson river; looking northward from West Point. The crystalline Highlands of the Hudson are cut across by a deep and narrow gorge, by which the open upper valley of the Hudson is drained. The whole region once stood lower, and was then worn down to a lowland of denudation whose remnants are now seen in the relatively even sky-line of the Highlands. The denudation of this lowland was completed in the later part of Cretaceous time. Somewhere in Tertiary time an elevation raised the lowland to about its present altitude, the uplift being greater in the north than in the south. In this slanting upland the Hudson cut down its valley, and the valley widened by the wasting of its sides. The depth of the valley is dependent simply upon the height to which the old surface was uplifted; the breadth of the valley depends upon the hardness of the rocks in which it was sunk. North of the Highlands the rocks are relatively weak; there the valley is wide. The Highlands are of hard rocks, and there the valley is narrow. The great volume of the present Hudson river is due to a slight depression of the land, whereby sea water is allowed to flood the valley for 150 miles from its mouth, as far as Albany. The Hudson proper above Albany is comparatively a small stream (W. M. D.).

445 (1315). Hudson river; looking southward past Poughkeepsie. Since the general elevation by which the Hudson cut its gorge through the Highlands and opened its wide valley from Newberg to Albany and beyond, there has been a later elevation of a less amount by which the valley-lowland above Newberg has been trenched by the river to a depth of 200 or 300 feet. Since then a slight depression has flooded the river with sea water, thus giving it a volume unduly great for its moderate drainage area. This view shows the Highlands in the distance. The valley-lowland of Tertiary denudation forms the sky-line of the foreground and middle distance. The trench cut into this lowland makes the center of the view, and in this trench the sea water is now admitted by the depression of the country (W. M. D.).

446 (1307). Hudson river; looking northward from fort Putnam.

447. Palisades of the Hudson; looking northward from Englewood cliffs. The Palisades represent the outcropping edge of an intrusive columnar sheet of Triassic lava. Their present comparatively even crest-line is a remnant of part of the lowland to which all this part of the country was reduced late in Cretaceous time. The valley of the Hudson (here seen to the right) and the lowlands of northern New Jersey (not here shown) west of the ridge result from Tertiary denudation since the uplift of the old Cretaceous lowland (W. M. D.).

448 (1308). Hudson river; looking southward from fort Putnam.

449 (1303). " " West Point; from fort Putnam.

450 (1326). " " " " steamboat "New York."

451 (1019). Chateaugay; from Chasm house.

452. Raquette lake; mouth of Marion river.

453 (737). Marion river; Bassett's camp.

454 (1378). Imbricating beach pebbles; at low tide in the bay of Fundy, 20 miles east of Saint Johns, N. B.

Photographed and Presented by Frederick H. Chapin, of Hartford, Conn.

Size, 5 x 8 inches. Published in part as illustrations of "Mountaineering in Colorado," 1890. (Mr. Chapin's photograph numbers are given in parentheses.)

455 (267). Pikes peak, Col.; looking northwestward from timber line on Bald mountain.

456 (25). Longs peak, Col.; looking north-by-west from Table mountain.

457 (13). " " " view from Key-hole, looking westward.

458 (19). " " " " " summit, looking westward.

459 (36). " " " lateral moraine.

460 (15). " " " view from Trough, looking northwestward. Fissured granite in right foreground.

461 (14). Longs peak, Col.; view from Trough, looking westward.

462 (50). " " " Lake (11,000) and Lily mountain, looking eastward.

463 (350). Uncompahgre peak, Col.; from the west on the divide.

464 (361). In the San Juan mountains; looking southwest-by-west toward Lone cone from the summit of Uncompahgre.

465 (345). View from the summit of Uncompahgre; looking westward.

466 (344). " " " " " " " west-by-north.

467 (352). Arête of mount Snaefel; San Juan mountains, Col.

468 (210). Ypsilon peak; from Deer mountain, Estes park, looking westward.

469 (214). " " Front range, Estes park.

470 (183). Estes park, Col.; view looking northwestward.

471 (62). " " and Deer mountain, Col.; view looking westward.

472 (90). " " " " " " " " eastward.

473 (438). Acowitz canyon, Col.; looking southwest.

474 (317). Cheyenne canyon.

475 (405). Alamo ranch and the Mesa Verde; Point lookout, near Mancos, Col.

476 (412). Ute Indians near entrance to Mancos canyon.

477 (447). The Cliff-palace, Cliff canyon; Mesa Verde, Col.

478 (456). " " " " " " "

479 (473). Crenelated fortress; Navajo canyon, Col.

Photographed and Presented by Professor Harry Fielding Reid, Case School of Applied Science, Cleveland, Ohio.

Nos. 480 to 498, size 6 x 8 inches; nos. 499 to 553, size $3\frac{1}{2}$ x $4\frac{3}{4}$, Kodak views. Professor Reid's numbers are given in parentheses. (Some of these views are published in Professor Reid's paper, "Studies of Muir Glacier," in the National Geographic Magazine, vol. iv, 1892, pp. 19–84, pls. 1–16.)

480 (207). Ice front of Muir glacier and delta of western subglacial stream.
481 (225) End of Muir glacier; from camp Muir, 1890.
482 (201). Mounts Case and Wright and Muir glacier; from C^7.
483 (200). " " " " " " " " "
484 (205). Ice front of Muir glacier; from near AB.
485 (206). " " " " " " camp Muir.
486 (204). Mounts Case and Wright; from near AB.
487 (214). White glacier; mount Case on right. An excellent general view of a glacier.
488 (203). Mount Wright; from shoulder of mount Case.
489 (216). Mount Young.
490 (221). Buried forest; looking eastward, mount Case in the distance.
491 (220). " " " westward.
492 (213). Moraine near end of Muir glacier.
493 (217). Limestone mountain and stranded iceberg; about 10 miles south of Muir glacier bay.
494 (208). Part of ice front of Muir glacier and stranded ice; from just under M.
495 (209). Wing of Muir glacier overriding roughly stratified deposits; on western shore of Muir inlet (published by H. P. Cushing in the American Geologist, vol. viii, 1891, p. 207).
496 (210). A stranded iceberg; a nearer view than 495.
497 (212). Pinnacles at the end of Muir glacier.
498 (211). " " " " " " "
499 (58). Diorite peaks; from Snow dome. C_2 is highest peak.
500 (119). Berg lake; from Tree mountain.
501 (118). Girdled glacier; from Tree mountain.
502 (36). Main valley; from Tree mountain.
503 (47). Looking down main valley from P. Tree mountain on extreme right, mount Young on extreme left.
504 (56). Looking down main valley from top of Snow dome. A_8 in middle and mount Young on left.
505 (8). Rock basin on top of Nunatak H; Muir glacier. The white surface to the left of the lake is rock in strong sunlight.
506 (61). First northern tributary; from Snow dome.
507 (45). View from P; White glacier on right, southeastern tributary on left.
508 (67). First northern tributary; from 5.
509 (38). View from Tree mountain; mount Young on right, main lake below it.
510 (103). Origin of western subglacial stream; Ridge at end of glacier.
511 (55). Looking up the southeastern tributary; from top of Snow dome.
512 (23). View from north; Snow dome in the middle, C_2 in distance.
513 (46). View from P, looking up southeastern tributary; Tree mountain on extreme left.

514 (12). Mount Case; from *E*, across Dirt glacier.

515 (22). View from north, showing mouths of Girdled glacier and Granite canyon.

516 (24). View from north, looking up first northern tributary.

517 (74). First northern tributary; from 5. Snow dome on right; Nunatak *I* on left in foreground.

518 (90). Looking across Dirt glacier from 5; N_7 in distance over saddle.

519 (87). Mount Wright; from 5.

520 (132). Upper part of Dirt glacier; from near 5.

521 (35). Southeastern tributary; from top of Tree mountain (*o*).

522 (37). Looking down main valley; from top of Tree mountain (*o*). A_8 in middle part of mount Young on left.

523 (33). Range of mountains separating White glacier from the southeastern tributary; taken from top of Tree mountain (*o*).

524 (41). Mount Young; from top of Tree mountain.

525 (72). Pyramid peak and Dying glacier; from 5. The distant mountains are on further side of Glacier bay.

526 (71). Western tributary; from *V*. *R*, ridge in middle.

527 (20). View from *N*: White glacier and Nunatak *I* on right; Nunatak *II* in middle; mount Young behind Tree mountain on left; A_8 in the distance in middle of picture.

528 (69). Looking up main ice stream of Muir glacier; from *V*. f_2 in middle distance.

529 (120). Berg lake; from lower down on Tree mountain, 1890.

530 (75). Nunatak *II* and moraines around it; from *V*.

531 (68). View from *V*; second northern tributary is behind mountains on the right; Black mountain on left; Nunatak *II* in foreground.

532 (73). Moraines: Granite canyon; from *V*. C_2 is just over Granite canyon; Girdled glacier partly seen on right.

533 (49). Girdled glacier and Granite canyon; from *P*. C_2 on left.

534 (21). View from north; mount Young in the distance.

535 (40). Girdled glacier and Granite canyon; from Tree mountain.

536 (18). Upper part of Glacier bay; from end of Headland island, 1890.

537 (16). " " " " " near Muir inlet, 1890.

538 (94). Delta of the eastern subglacial stream at low tide: from camp Muir, 1890.

539 (5). Part of ice front of Muir glacier, 1890.

540 (7). Pinnacles of ice at end of Muir glacier, 1890.

541 (30). Ice front of Muir glacier; from the west. Mount Case in the background.

542. " " " " from *V*, Sept. 7, 1890.

543 (85). " " " " " " " (nearer view).

544 (93). Station *E* (under cross); seen from camp Muir.

545 (104). Morainal ridge.

546 (130). Big rock on moraine.

547 (133). Cone of rounded stones; just south of C_7 on Muir glacier (see 550).

548 (128). Moraine coming out of Main valley; view looking into Main valley.

549 (131). Big rock on moraine.

550 (134). Another view of cone of rounded stones (see 547).

551 (70). Northwestern tributary; from *V*. C_7 in foreground on right; Gable mountain in distance in middle.

552 (10). Some moraines on Muir glacier. Nunatak *I* and snow dome seen from *E*.

553 (26) View from north Black mountain.

Presented by the United States Geological Survey; J. W. Powell, Director.

The 51 views numbered 554 to 604, inclusive, are 6 x 8 inches.

Photographed by I. C. Russell, 1891.

554. Mount St. Elias: from western end of Samovar hills. Agassiz glacier in the foreground.
555. Southern face of mount St. Elias.
556. Ice cascade in Agassiz glacier, partially covered by new snow.
557. Cascade in the névé of Newton glacier.
558. " " " " of a tributary of Agassiz glacier.
559. Canyon in the Chaix hills. Stratified moraine material containing recent sea shells.
560. View from the summit of Chaix hills; looking eastward over Malaspina glacier.
561. Mount St. Elias; from Malaspina glacier south of Chaix hills. Southern escarpment of Chaix hills in middle distance.
562. Marginal drainage, southern base of Chaix hills, looking westward. Moraine-covered border of Malaspina glacier on the left and scarp of gravel terrace on right.
563. Abandoned lake beds; south side of Chaix hills. The lake is retained by Malaspina glacier.
564. Yahtse river; from above ice tunnel, looking southward.
565. " " issuing from a tunnel in Malaspina glacier. The bluffs are of dirt-covered ice.
566. Moraine-covered surface of Malaspina glacier; near point Manby.
567. Surface of central portion of Malaspina glacier.
568. Alluvial fan now being formed by esker streams: western side of Yakutat bay.
569. View from southern margin of Malaspina glacier; showing country recently abandoned by ice.
570. Sitkagi bluffs: Southern margin of Malaspina glacier. The glacier, heavily laden with moraine, has been cut away by the sea.
571. Vegetation on Malaspina glacier; 4 miles from its southern border.
572. Surface of alluvial fan of the Yahtse; showing partially buried forest.
573. Icebergs stranded at low tide; shore of Yakutat bay.
574. Tree broken by recent advance of Malaspina glacier; near point Manby.
575. Vegetation about southern border of Malaspina glacier.
576. Southern margin of Malaspina glacier; showing forest growing on the glacier.
577. Second view of alluvial fan on esker stream.
578. Glaciated surface on Haenke island; probably covered by ice less than 150 years ago.
579. Dalton glacier; from Haenke island, Disenchantment bay.

Photographed by C. D. Walcott, September, 1891.

580. Lace falls; Cedar creek, one mile above Natural bridge, Va.
581. Natural bridge, Virginia: Distant view looking westward.
582. " " " from southeastern side.
583. " " " " northwestern side, looking through arch.
584. " " " " southeastern side.

585. Erosion of slaty banded limestone; bed of Cedar creek, about one mile below Natural bridge, Va.

586. Plicated slaty limestone; same locality as 585.

587. Contorted slaty limestone; same locality as 585. Massive limestone in foreground.

588. Folds in Cambrian shales; northern bank of Cedar creek, one and a half miles below Natural bridge, Va.

589. Folds in Cambrian sandstones and shales; railroad cut about one and a half miles above Hampton, Tenn., on Doe river.

590. Compressed anticlinal and fault plane in Nashville sandstone; near western end of Little river gap, Chilhowee mountain, Tenn.

591. Cliff of Cambrian sandstones; southern side of Doe river gorge, about two miles above Hampton, Tenn.

592. Cliff of Cambrian sandstone; northern side of Doe river gorge, about two miles above Hampton, Tenn.

Photographed by W. H. Weed, 1891.

593. Lakelet in moraine; Little Timber creek, Crazy mountains, Mont.

594. Amphitheater at head of Little Timber creek.

595. Lake " " " " " " occupies a rock basin.

596. Crags of Laramie conglomerate; Brackett creek, Montana. Same rock as seen in 597.

597. Laramie conglomerate: formed of pebbles of volcanic rocks; Brackett creek, Park co., Mont.

598. Morainal débris; characteristic of mountain moraine of Crazy mountains, Mont.

Photographed by J. Stanley-Brown, 1891.

599. Seal rookery; shore of Saint Paul island, Pribylov group, Alaska.

600. Crater lake; 300 feet above sea, Saint Paul island, Pribylov group.

601. Black bluff; Fossil-bearing tuff of Cinder cone, Saint Paul island.

602. " " " " " " " " " " "

603. Contact of two basalts; Black bluff, Saint Paul island.

604. Fault in calcareous clays and sands; eastern side of Rio Verde, 8 miles below camp Verde, Arizona (photographed by Cosmos Mindeleff).

Presented by the Geological Survey of Canada; Dr. Alfred R. C. Selwyn, Director, Ottawa, Canada.

Sizes of photographs: 605 to 630, 6½ x 8; 631 to 635, 11 x 14. (Original numbers in parentheses).

Photographed by Dr. Geo. M. Dawson.

605 (57, Sept. 16, 1889). Fraser river; Fountain, British Columbia. Showing depth of post-glacial excavation in glacial deposits with which the valley has been partly filled.

606 (79, Aug. 27, 1890). Part of the Interior plateau of British Columbia; looking southeastward from Porcupine ridge (altitude, 6,030 feet).

607 (77, Aug. 26, 1890). Glaciated surface of basalt; illustrating action of part of the great Cordilleran glacier, flowing southeastward at a height of 5,930 feet above sea-level.

608 (31, 1883). Gorge of Elk river; western flank of Rocky mountains, British Columbia. Cut through flat-lying lower Cambrian quartzites.

609 (50, Sept. 23, 1884). Glacier and snow-field at head of Red Deer river; Rocky mountains, Alberta.

610 (41, Sept. 20, 1884). Folded Cretaceous rocks (Kootanie formation); headwaters of Cascade river, Rocky mountains, Alberta.

611 (17, June 27, 1883). Bluffs on Pelly river; Lethbridge, Alberta. Illustrating the arrangement of the glacial deposits. *A*. Quartzite shingle, etc ("Saskatchewan gravels"); *B*. Lower bowlder clay; *C*. Interglacial beds, elsewhere holding peat, and overlain in distant bluffs by upper bowlder clay (see Report of Progress, 1882–'84, p. 139 C).

Photographed by J. B. Tyrrell.

612 (10, 1887). View northward along one of the upper lake Agassiz beaches; east of Duck mountain, Manitoba.

613 (6, 1889). Swampy island; lake Winnipeg, Man. Face of cliff showing bowlder of gray gneiss lying on striated Trenton limestone, overlain by loose blocks of Trenton limestone; probably an old beach deposit.

614 (9, 1889). Swampy island; lake Winnipeg, Man. Cliff of Trenton limestone, overlain by broken but somewhat rounded fragments of same rock; probably an old shore-line.

615 (88, 1889). Upper limestone of the Devonian of Manitoba; Rose island, Swan lake, Man.

616 (96, 1889). Dakota sandstone, weathered out into rounded masses near an old lake Agassiz shore-line; Kettle hill, Swan lake, Man.

617 (103, 1889). Ice-pressed bowlder pavement; southern shore of Red Deer lake. Saskatchewan.

618 (30, 1890). Cliff of Niagara dolomite; Cedar lake, Saskatchewan.

619 (50, 1890). Trenton limestone; northwestern shore of lake Winnipeg.

620 (57, 1890). Laurentian gneiss; southern shore of Little Playgreen lake, in front of Norway house. Showing characteristic rounded and lumpy surface.

621 (2, 1890). View of cliff on northern side of Deer island, lake Winnipeg, Manitoba. Saint Peter sandstone, capped by Trenton limestone (photographed by D. B. Dowling).

Photographed by T. C. Weston.

622 (13, 1879). Magdalen river and bay; lower Saint Lawrence. Showing characteristic gravel ridge of estuaries of parts of Gulf of Saint Lawrence and Newfoundland.

623 (9, 1873). Lower Helderberg rocks; Arisaig, Nova Scotia (see Geological Survey Report, vol. ii, pp. 37 P and 48 P).

624 (8, 1873). Lower Helderberg rocks; Arisaig, Nova Scotia. Showing ripple-markings.

625 (18, 1873). Lower Carboniferous deposits; Arisaig coast, Nova Scotia. Showing thick band of Oolitic limestone.

626 (21, 1879). Carboniferous rocks; southern shore, Joggins, Nova Scotia. Showing erect *Sigillaria* (see Acadian Geology).

627 (24, 1879). Carboniferous rocks; southern shore, Joggins, Nova Scotia (see Acadian Geology).

628 (14, 1879). Lower Cambrian rocks (gold bearing); "The Ovens," Lunenburg co., Nova Scotia.

629 (8, 1889). South Saskatchewan river; above Battleford crossing, N. W. T. River valley of the plains excavated in Cretaceous rocks.

630 (11, 1873). Pre-Cambrian contorted schists: Shipton, Me. (see Geol. Survey Report, 1886, vol. ii, p. 35 J).

Photographed by R. W. Ells.

631. Twisted gneiss; southern shore of Ottawa river, opposite Montebello.
632. " " " " " " " " "
633. " " " " " " " " "
634. " " northern " " " " " Papineauville.
635. " " " " " " " " "

The following resolution, presented by Mr. Arthur Winslow, was adopted unanimously:

Whereas our fellow-member and esteemed colleague Professor Edward Orton is, through serious illness, unable to be with us: Therefore—

Resolved, That the Secretary be requested to convey to Professor Orton an expression of our sincere sympathy and of our deep regret that he cannot be present at this meeting; that we miss his genial presence and deplore the fact that through his absence we lose much that he might tell us of interest and value concerning the regions about us, his field of work, in which he has developed so much or splendid value to our science.

That we rejoice, however, in being able to congratulate him on his rapid convalescence, and that we look forward hopefully to seeing him in our midst at an early future meeting.

The Chair announced that the Summer Meeting would be held in Rochester, N. Y., the precise date in August to be announced hereafter by the Council.

It was also announced that there would be no evening session of the Society, but that the Fellows would dine at the Neil house.

The remainder of the morning session and the entire afternoon session were devoted to the reading of papers. The first paper was entitled:

NOTES ON THE GEOLOGY OF THE VALLEY OF THE MIDDLE RIO GRANDE.

BY E. T. DUMBLE.

The paper was discussed by W J McGee, who remarked:

Recent observations by Mr. R. T. Hill and myself corroborate Mr. Dumble's conclusions. We find the peculiar deposit called the Reynosa marl to extend far beyond the Rio Grande into Mexico with unchanged characters, and to stretch also far northeastward but with gradually changing characters until a part at least of the series grades into the Lafayette formation of the Mississippi embayment and the eastern Gulf and Atlantic slopes. In Mexico and Texas and further northeastward alike, the Reynosa and its homologue, the Lafayette, are the newest formations of the province except the Columbia; and the Columbia is separated from

the Lafayette-Reynosa by a strong unconformity representing erosion many times, perhaps many hundred times, greater than that of the post-Columbia period. Throughout the greater part of the province there is a still more noteworthy unconformity below the Lafayette; but this unconformity has not yet been so clearly recognized in Texas, where indeed there is reason for believing it to be of diminished magnitude.

This paper forms pages 219–230 of this volume.

The next communication was entitled:

A REVISION AND MONOGRAPH OF THE GENUS *CHONOPHYLLUM*.

BY W. H. SHERZER.

Remarks were made by Alpheus Hyatt. The paper is published as pages 253–282, with plate 8, of this volume.

Announcements were made by the President and Secretary, and the Society adjourned for the noon recess.

The Society reassembled at 2 o'clock p. m. and listened to a paper read, in the absence of the author, by W J McGee:

RELATIONSHIP OF THE GLACIAL LAKES WARREN, ALGONQUIN, IROQUOIS AND HUDSON-CHAMPLAIN.

BY WARREN UPHAM.

(*Abstract.*)

These names, excepting the last, which has not been before used, were proposed by Professor J. W. Spencer, in 1888, for the most important and distinctly defined stages of the formerly larger bodies of water that have occupied the basins of the great Laurentian lakes since the deposition of the drift. Their shore lines, high above the present lakes, are clearly marked by beach ridges and eroded cliffs. Large portions of the old beaches and of the enclosed lacustrine tracts have been mapped by the geological surveys of Ohio and Wisconsin and by Professor Spencer and Mr. Gilbert, both of whom have recently made important contributions to the discussion of the history of these lakes, concerning which also Lyell, Chapman, Fleming, Whittlesey, Newberry, Claypole, and others had written earlier. Spencer holds that these bodies of water were held by barriers of land, so far as they were true lakes, while he would refer some of the old shore lines to depression of the land so low as to permit them to be formed by the sea. Mr. Gilbert, on the other hand, attributes these ancient lakes to the barrier of the ice-sheet during its recession at the close of the Glacial period, their changes in area and their reduction from higher to lower levels being due to the gradual uncovering of the land from the ice by which it had been enveloped, opening thus successively lower outlets.

With this latter explanation I fully agree, and therefore place the descriptive word "glacial" before the names of these lakes.

In a paper read a year ago before this Society I presented a general review of the glacial lakes of Canada, in which the relationship of lakes Warren and Iroquois and the sea level in the Champlain epoch was found to imply for the Chicago outlet of lake Warren nearly the same altitude as now, or about 600 feet above the sea. It was also shown that lake Iroquois, while outflowing at Rome, New York, was at first probably 100 feet or less above the sea, but that its basin was uplifted, while its outlet continued at Rome, until the height of this lake was about 300 feet above the sea. The present paper, which is supplementary to that of last year, after briefly noticing the three glacial lakes Warren, Algonquin and Iroquois in the basins of the great Laurentian lakes, is chiefly designed to call attention to the expansion of lake Iroquois until it became united with the glacial lake which filled the valley of the Hudson and the basin of lake Champlain.

Lake Warren was contemporaneous with the glacial lake Agassiz, which occupied the basin of the Red river of the North and the district of the present great lakes of Manitoba, and it may have continued until lake Agassiz began to outflow northeastward. It belonged to stages in the departure of the ice-sheet which appear to have permitted confluent sheets of water to stretch as a single lake from the western end of the basin of lake Ontario over the whole or the greater part of the four higher Laurentian lakes. Its outlet was across the watershed near Chicago, between lake Michigan and Des Plaines river, at a height of about 12 feet above this lake and 595 feet above the sea, where now a canal has been cut through on the same level with the lake.

Lake Algonquin, which was the reduced representative and direct descendant of the somewhat earlier lake Warren, occupied the basin of Georgian bay and lake Huron and perhaps portions of the basins of lakes Michigan and Superior. It outflowed for some time through Balsam lake and the river Trent to lake Iroquois, then restricted to the lake Ontario basin. Later it was tributary by the way of lake Nipissing and the Mattawan river to the northward expansion of lake Iroquois, then filling the lower part of the Ottawa basin. The altitude of lake Algonquin above lake Iroquois in their earlier stages was approximately 200 feet, and in the later stages of both these lakes it was probably 50 to 150 or 200 feet, increasing with the gradual uplifting of the country between lake Huron and the Saint Lawrence.

Lake Iroquois began to exist as soon as the recession of the ice-sheet uncovered the Mohawk valley. The previously existing lake Warren was then drawn down below the avenue of outflow at Chicago, and became changed, as Mr. Gilbert has shown, into lakes Algonquin and Iroquois, the former either extending from the basin of lake Huron into those of lakes Michigan and Superior or receiving tributary rivers from those lakes, and the latter filling the basin of lake Ontario and receiving the outflow from the former. In mapping the highest shore of lake Iroquois in the Ontario basin, Professor Spencer calls this the western portion of lake Iroquois, and states that this lake spread to the northward and eastward over the great triangular area between the Ottawa and Saint Lawrence rivers, sending an arm far up the Ottawa valley.

But none of the writers on these glacial lakes have studied the question, Where was the ice-sheet latest a barrier across the Saint Lawrence basin? The directions of glacial striæ and transportation of drift answer that the ice-sheet in this region during the closing stage of glaciation was thickest on a belt crossing the Saint

Lawrence nearly from east-southeast to west-northwest in the vicinity of Quebec. Thence its currents pushed up the valley by Montreal, and also down the valley, filling the broad estuary of the river to the gulf; and on that tract, at or near Quebec, doubtless the last remnant of the ice-barrier was melted away, allowing the sea ingress westward to lake Champlain, to the mouth of lake Ontario, and to Allumette island in the Ottawa. Previous to this, while an arm of the sea had been washing the ice-border and thus increasing its speed of retreat in the gulf of Saint Lawrence and westward to Quebec, the waves of lake Iroquois on the other side of the narrowing ice-belt in this valley had likewise hastened its departure. Gradually this lake had extended beyond the basin of lake Ontario to fill at length the lower part of the Ottawa basin, probably to the mouth of the Mattawan and possibly at first even crossing the watershed east of lake Nipissing, becoming thus confluent with lake Algonquin—that is, the Georgian bay and lake Huron of that time. It had spread eastward around the northern side of the Adirondacks to lake Champlain and Montreal, and down the Saint Lawrence valley probably almost or quite to Quebec, when the ice-dam between it and the sea disappeared. The glacial lake Iroquois, until this time outflowing to the ocean by the Hudson river, then ceased to exist; lake Ontario became a separate sheet of fresh water; and the sea, at a somewhat lower level than lake Iroquois had held, stretched to the Thousand islands, where the Saint Lawrence river, at first only a few miles long and with scarcely perceptible fall, discharged the outflow of lake Ontario into the prolonged gulf of Saint Lawrence.

Another part of this theme remains to be added, telling the history of the continuous Hudson and lake Champlain valley during the recession of the ice-sheet up to the time of this opening of its northern portion to the ocean. The absence of marine fossils in beds overlying the glacial drift on the shores of southern New England, Long island and New Jersey, and the water-courses which extend from the terminal moraine on Long island southward across the adjacent modified drift-plain and continue beneath the sea level of the Great South bay and other bays between the shore and its bordering long beaches, prove that this coast stood higher than now when the ice-sheet of the last glacial epoch extended to its farthest limit. A measure of this elevation of the seaboard in the vicinity of New York during the Champlain epoch is supplied, as I believe, by the shallow submarine channel of the Hudson, which has been traced by the soundings of the United States Coast Survey from about 12 miles off Sandy Hook to a distance of about 90 miles southeastward.* This submerged channel, lying between the present mouth of the Hudson and the very deep submarine fjord of this river, ranges from 10 to 15 fathoms in depth, with an average width of 1¼ miles, along its extent of 80 miles, the depth being measured from the top of its banks, which, with the adjacent sea-bed, are covered by 15 to 40 fathoms of water, increasing southeastward with the slope of this margin of the continental plateau.

During the whole or a considerable part of the time of the glacial lake Iroquois this area stretching 100 miles southeastward from New York was probably a land surface, across which the Hudson flowed with a slight descent to the sea. But northward from the present mouth of the Hudson the land in that epoch stood lower than now; and the amount of its depression, beginning near the city of New York

*A. Lindenkohl, Am. Jour. Sci., 3d series, vol. xxix, 1885, pp. 475–480, and vol. xli, 1891, pp. 489–499; J. D. Dana, Am. Jour. Sci., 3d series, vol. xl, 1890, pp. 425–437, with map reduced from a chart of the United States Coast Survey.

and increasing from south to north, as shown by terraces and deltas of the glacial lake Hudson-Champlain, which were formed before this lake became merged in lake Iroquois, was nearly 180 feet at West Point, 275 feet at Catskill, and 340 feet at Albany and Schenectady.* Farther northward, according to measurements by Baron de Geer of the altitudes of the highest shore marks in the part of the Saint Lawrence basin which was filled by the expanded lake Iroquois, the depression was approximately 650 feet at St. Albans; 625 feet on mount Royal at Montreal; and 700 feet on the hills a few miles north of the city of Ottawa. From these figures, however, both in the Hudson and Saint Lawrence basins, we must subtract the amount of descent of the Hudson river, which in its channel outside the present harbor of New York may probably have been once 50 or 60 feet in its length of about 100 miles, as seems to be indicated by the height of terraces on Manhattan island and in its vicinity. Before the time of disappearance of the ice-barrier at Quebec this descent may have been diminished, or the seaboard at New York may have sunk so as to bring the shore-line nearly to its present position; but the Hudson valley meanwhile had been uplifted, so that an outflow from lake Iroquois crossed the low divide, now about 150 feet above the sea, between lake Champlain and the Hudson. This is known by the extension of fossiliferous marine deposits along the lake Champlain basin nearly to its southern end, while they are wholly wanting along all the Hudson valley. Indeed, the outflowing river from lake Iroquois, or the Hudson during the subsequent post-glacial epoch, channeled the lower part of this valley to a depth of about 100 feet below the present sea-level, proving that the land there, as Mr. Merrill points out, stood so much higher than now at some time after the ice retreated.

When lake Iroquois ceased to outflow at Rome and, after intervening stages of outlets existing for a short time at successively lower levels north of the Adirondacks, began to occupy the lake Champlain basin, outflowing thence to the Hudson, its surface fell by these stages about 250 feet to the glacial lake Hudson-Champlain, which had doubtless reached northward nearly to the Saint Lawrence. After this reduction of its level, lake Iroquois had a depth of about 150 feet over the present mouth of lake Ontario, as shown by a beach traced by Mr. Gilbert, which thence rises northeastward but declines toward the south and southwest. Its plane, which is parallel with the higher Iroquois beaches, sinks to the present lake level near Oswego, New York. Farther southwestward the shore of the glacial lake at this lower stage has been since submerged by lake Ontario. The Niagara river was then longer than now, and the lower part of its extent has become covered by the present lake. From the time of the union of lakes Iroquois and Hudson-Champlain a strait, at first about 150 feet deep, but later probably diminished on account of the rise of the land to a depth of only about 50 feet, joined the broad expanse of water in the Ontario basin with the larger expanse in the Saint Lawrence and Ottawa valleys and the basin of lake Champlain. At the subsequent time of ingress of the sea past Quebec the level of lake Iroquois again fell probably 50 feet or less to the ocean level. The place of the glacial lake so far westward as the Thousand islands was then taken by the sea, with the marine fauna which is preserved in the *Leda* clays and *Saxicava* sands.

*J. S. Newberry, Popular Science Monthly, vol. xiii, 1878, pp. 641–660; F. J. H. Merrill, Am. Journ. Sci., 3d series, vol. xli, 1891, pp. 460–466; W. M. Davis, Proceedings of the Boston Society of Natural History, vol. xxv, 1891, pp. 318–331; Warren Upham, Bull. Geol. Soc. Am., vol. 1, 1890, p. 566, and vol. 2, 1891, p. 265.

In connection with the above the two following papers were read:

THE IROQUOIS SHORE NORTH OF THE ADIRONDACKS.

BY J. W. SPENCER.

In previous papers on the Iroquois shores of the Ontario basin, their position was definitely located only to a point near Belleville, on the northern side of lake Ontario. But, from the general character of the country, I pointed out the necessity of extending the Iroquois water across a broad expanse of country to the highlands north of the Ottawa river, on the flanks of which shore deposits are known at various localities. I have also shown that the Iroquois water stood at or near sea-level; and in my working hypothesis considered the Iroquois water as an extension of the gulf of Saint Lawrence into the Ontario basin, although more or less obstructed by ice. Since the last paper was written, Mr. G. K. Gilbert and myself have revisited the region as far as a point 100 miles northeast of Watertown. Owing to Mr. Warren Upham's recent acceptance of the extension of the open Iroquois water as far as Quebec, it becomes desirable that the old shore line, so far as definitely surveyed, should be published.

After a long stretch of unbroken continuity, the Iroquois beach is abruptly interrupted by rocky cliffs on the side of the escarpment about 5 miles east of Watertown. Beyond this point, owing to the broken continuity, the remnants of the ancient shore are more or less fragmentary. The old subaqueous plain extends up the broad Black river valley far above Carthage, with gravel deposits characterizing portions of its margin. The northeastward elevation of the Iroquois beach in this region rises at from five to six feet per mile. Beyond Carthage, the country becomes more broken, being traversed by ridges of crystalline rocks, forming a late extension of the archipelago of the Thousand islands at a higher level. The drift deposits become more sandy, with very little clay, and consequently are less favorable for the production of well defined beaches. The island character of this region is particularly unfavorable for the development of well defined shore markings. But wherever valleys enter the archipelago, their outlets are characterized by delta deposits or terraces, whose hypsometric position can be predicted in proceeding eastward.

At Mr. Frank Wilson's, 4 miles east of Watertown, the unquestioned beach is broken into ridgelets between 730 and 704 feet, with a frontal gravel-bearing terrace at 682 feet. Below this horizon there is an extensive terrace plain east of Watertown at about 535 feet. At the mouth of Indian river, at Natural bridge, these delta deposits form terraces, with more or less beach structure, at an elevation between 829 and 802 feet, with a frontal gravel plain descending from 787 feet downward. In both cases, the waves, in carving out the lower terraces, have removed portions of the higher ridgelets. Between these limits there is no strongly marked terrace, but the lower is more confined to this regional topography than the upper; and where gravelly, the pebbles are subordinate to the sand. For quantity and size of water-worn pebbles, the gravel deposits at Natural Bridge are physically the equivalents of those of the Iroquois beach to the southwestward. Above and below this level, at Natural Bridge, there are no fragments of ancient water lines liable to be mistaken for the Iroquois level. The elevation of these deposits is that which would be expected from the measured warping recorded about Watertown.

Beyond Natural Bridge there are extended gravel plains, in height conforming to the terraces at the old mouth of Indian river; but these are often more or less pitted.

These plains appear to me as due to the presence of floebergs or other masses of ice stranded upon the old shore. Even if they were shore deposits formed in glacial lakelets, their elevation is such as to show a common water level. They now face a lower descending country to the northwestward, and are deformed by the gradual warping toward the northeast. At Pitcairn, the valley is 200 feet or more in depth, forming a deep channel in the late expansion of the Laurentian archipelago. High on the sides of the valley zones of bowlders, which are so often characteristic of old shore lines, are found at heights in keeping with the deformed Iroquois beach.

A little north of East Pitcairn, there is a fine display of terraces, with beach structure. These are partly in front of a now unimportant valley. There are several ridgelets, the highest being 942 feet; but the most important is 930 feet above tide. These ridgelets descend to a terrace or frontal plain 60 feet below. A short distance beyond, the terraces of Oswegatchee river are seen. Just north of Fine, they close around and connect a rocky island with the eastern side, and form a sort of barrier beach. This bar has an elevation of 972 feet. All of the above-recorded terraces were leveled. The following are of barometric measurement. The rise in height in these beaches corresponds to the deformation of the Iroquois beach, increasing from five to six feet or more for miles toward the northeast, which amount ought perhaps to be slightly modified, owing to imperfect identification in the crests of these terraces or the absence of some portions of the highest ridgelets.

The next great valley is that of Grassy river. At Clifton Forge (Clarksboro), the old mouth of the valley is well defined by a beautiful gravel terrace at 1,055 feet (bar.), with an inferior terrace or ridge at 45 feet below. Lower than this no well marked gravel terrace occurs; but at 850 feet there is an extensive sand plain, forming a terrace confined to the valley. The terrace in the last valley is nearly due north of that at Fine, and appears to represent a warping of eight feet per mile, but probably the barometric measurement is responsible for the apparent increase in rate of elevation. Still, the northern uplift may probably exceed that to the northeast.

The chain of observation was continued by Mr. Gilbert and myself to Racket river. The elevations were not satisfactorily obtained, as the changing weather greatly affected the barometer, especially above South Colton. At South Colton, there is a sandy plain at about 940 feet (bar.), apparently corresponding to the plains below Clifton Forge and Fine. Racket river presents an interesting change of channel near Stark post office. Its old course was in a broad valley, now occupied by Coldwater creek as far as South Colton; but after the Pleistocene revolution, it cut across hard rocks and deserted its old channel. Following up the Coldwater valley, we reached a broad sandy terrace underlain by gravel. This plain forms terraces extending northward along the sides of the valley. Its elevation is 1,215 (? bar.; the weather was very threatening). Other deposits were noted at 1,350 feet, which were probably older river terraces. Again, on the brow of the plateau facing Potsdam, there was a plain at 1,160 feet with a bowlder pavement in front of it. The value of these measurements is so impaired that they are only important in identifying continued elevations of the terrace plains near the late outlets of the valleys as far eastward as Racket river. In descending from the last

plain there was no extensive valley terrace below the level of South Colton of magnitude corresponding to those at Watertown or at Clifton Forge. It might be noted that throughout this high region all of the pebbles are of local origin and none that could be identified as Canadian. The Paleozoic rocks were absent from the drift above South Colton and Parishville. Indeed, some of the apparent sandstones are cleavable quartzitic gneisses, and require close observation to prevent mistake.

Along the whole northern flank of the Adirondacks, there is a great poverty of glaciated surfaces. Near Natural Bridge the direction of the striæ was south 75° west and south 55° west. On the hills farther south the direction was south 20° to 25° east, and near Harrisville south 10° west. Bowlders were of large size. One, at a school-house three miles southwest of South Colton, showed at least 6,000 cubic feet above surface of the ground.

From the recent explorations, allowing for errors in observation and measurement, it appears that shore deposits occur at the mouths of all the valleys which entered the Laurentian archipelago of the Thousand islands. Throughout a considerable range of altitude, there is only one set of terraces or delta deposits, *always* occurring at the mouths of old valleys, with occasional connecting gravel plains or terraces of beach-like structure, composed of coarse pebbles, in magnitude comparable to the physical development of the Iroquois beach farther westward; the lower terraces being mainly sandy and confined to the valleys; and the higher, if known at all, much above the possible altitude of the Iroquois plain. These terraces form sets of ridgelets ranging downward from their crests about 50 feet to the gravelly deposit of their frontal terraces. This holds true alike for the exposures of the Iroquois beach east of Watertown and for the recorded terraces at the mouths of the valley. The next great terrace plain below these gravel shores is about 200 feet and mostly sandy, alike near Watertown and along Grassy river and elsewhere. The differential rise of the Iroquois beach increases toward the northeast. Southeast of lake Ontario it is three feet per mile. At Watertown it is five or, rather, nearly six feet, and eastward the terraces at the mouths of the valleys rise from six to perhaps eight feet per mile in a constantly increasing ratio, as would be expected.

Of all this cumulative evidence, there seems but one explanation, namely, that these shore accumulations at the mouths of the old valley are identical with the Iroquois beach further westward and formed one water level. The warping of this region is established, and cannot be discarded in order to have glacial dams at various elevations, which of itself appears unnecessary and illogical. But ice obstructions between these valleys at the same level would not permanently affect the water level of the whole; for glacial lakes are evanescent, and some of such, if they existed, would not have been more than narrow tongues, as shown by the incomplete surveys. I do not here accept or deny the occurrence of local glacial dams; only the identity of these deposits as the equivalent of the Iroquois shore seems well established for a hundred miles east of Watertown.

Mr. Upham's recently adopted hypothesis* of the extension of open water as far as Quebec during the Iroquois history, and the consequent shrinkage of the theoret-

* Mr. Gilbert informs me that Mr. Upham refers to beaches lower than the Iroquois as defined by me in naming that shore. One is scarcely expected to alter a definition. However, it makes but little difference which of the Ontario beaches he extends to Quebec, as all are far above the Champlain level.

ical glacial dams 400 miles to the northeastward, is in harmony with my views previously set forth. The details in the present paper only locate the approximate positions of the old shore as far northeastward as they have been definitely explored. Where the upward warping ceases or is replaced by a descending movement toward the sea has not been discovered, so that it may be found that the Iroquois shore is lower in the region of Quebec than in the Adirondack region. This idea of a lesser continental uplift in the northeast than farther southwestward has already been hypothesized in one of my previous papers and subsequently pointed out by Baron de Geer.

That much drifting ice occurred in the northeastward extension of the Iroquois water is probable on account of its pitted shores, bowlder pavements and broken features. It may be even possible that this body of water, which was at sea-level, was cut off from open water by local glaciers descending into the lower Saint Lawrence valley, but these could not be sufficient to hold for ages a body of water 600 miles long and in part over 100 miles wide much above sea level.

In Mr. Upham's paper on lakes Warren, Algonquin and Iroquois he has given definitions differing from those of my original descriptions. I described lake Warren as extending over the Ontario basin as well as over the basins of the upper lakes, for I know of terraces and other shore phenomena belonging to the elevation. The only systematic work on the Algonquin water was originally done by myself and recently continued by Mr. Taylor, and I have shown that its level was about 300 feet above the Iroquois plain. The dismemberment of the Warren water was first pointed out by myself and, from the evidence, there appear to have been many outlets—that at Chicago being only one of them and not the outlet of a separate glacial lake.

Mr. Gilbert's interpretation of the phenomena north of the Adirondacks as being attributable to glacial lakes does not seem to me to be tenable, from the immense amount of cumulative evidence set forth in this paper; but all the glacial characteristics of the terraces and pitted plains may be easily explained by floating ice, acting in the Laurentian archipelago upon the Iroquois shore; which would only be located as above described even upon Mr. Upham's explanation of the closing of the Ontario basin by a glacial dam at Quebec.

CHANNELS OVER DIVIDES NOT EVIDENCE PER SE OF GLACIAL LAKES.

BY J. W. SPENCER.

The locality of this paper was visited in company with Mr. G. K. Gilbert, and the descriptions given are only sufficient to allow a statement of my views, as I consider it a very important region.

The valley of Black river, New York, extends nearly 40 miles above Carthage, forming an embayment on the northern flanks of the Adirondack *massif*. Boonville is on the divide between the head of this valley and an eastern branch of the Mohawk river. The limestone floor of the divide is 1,141 feet above the sea. From it the valley rapidly widens, and at a point ten miles to the south it is two miles in width. At a short distance farther southward, the hills rapidly fall away, leaving a comparatively low country. A few miles westward, the parallel Iroquois beach records differential elevation of the land amounting to four feet or more per mile. In the great valley of the Black river, conspicuous terraces occur north of Boonville

at 1,190, 1,170 and 1,130 feet. The terraces continue on the southern side of the divide, and at a point ten miles distant were noted at 1,005, 970, 940, 888 and 830 feet, with the floor of the valley 770 feet above tide. With the differential warping considered, the identity of the upper terraces is unquestionable. The summit of the divide is not covered with a gravel deposit; but a short distance southward gravel deposits were seen, though their altitude was not measured.

Let us now ask, What barrier retained the volume of water 325 feet above its floor in a valley one to two miles wide, with the opening country descending in the next ten miles another 325 feet? Here we have the action of water in a great open embayment leaving records at an elevation of 650 feet without any barrier on the south, unless these waters were retained against the now high level banks, owing to a submergence of the region down to sea-level, as it can scarcely be supposed that a glacial dam could have occurred upon the southern side of a lake. The absence of the terrace deposits on the divide is easily explained by the action of tidal currents and need not be considered the proof of a glacial river flowing over the watershed into a great embayment which could not have retained the volume of water passing over the divide at hundreds of feet above the bottom of the valley without an obstruction or submergence to the south. The lower terraces are confined to the valleys and are not specially considered. Here, then, we find a col connected with terraces on the northern side, such as are often quoted as proof of glacial dams, but the terraces on the southern side disprove the efficiency of ice dams to account for this class of high level terraces.

Professor C. W. Hall was called to the chair, and discussion on the matter of the three preceding papers occurred, participated in by W J McGee, G. K. Gilbert, J. E. Wolff, I. C. Russell, G. F. Wright and J. W. Spencer. Mr. Gilbert spoke as follows on Dr. Spencer's papers:

The Iroquois shore-line or group of shore-lines has been traced about three-fourths of the Ontario basin. At the west it lies 100 feet above the modern lake, and it rises toward the northeast. On the northeastern side it has not been traced, and in that direction there is no land high enough to receive it. As I interpret the phenomena, the Iroquois water was retained on that side by a glacier occupying the Saint Lawrence valley, and its surface level was determined by the altitude of a divide at Rome over which the surplus water found outlet, flowing eastward down the Mohawk valley. It is Dr. Spencer's view that the Iroquois water stood at the level of the sea, the land being depressed at that time. Tracing the shore-line about the southern and eastern sides of the basin, I was able to map it to the vicinity of Watertown, where it turns northeastward, but a few miles beyond I found the record faint and finally untraceable. At the point where continuous observation ceased to be practicable the surface of the country is not well suited to the preservation of a shore record. It consists of a broad plain of sand with so little admixture of finer material that it is the prey of the wind and is re-sculptured into dunes. It seemed possible that beach ridges might have been formed upon this sand plain and afterward obliterated. A detour was accordingly made and the country beyond the sand plain was examined through a range of altitude including that of the Iroquois beach, in the hope of picking up its record once more and following it eastward; but it was not discovered, although the ground appeared favorable for the reception and preservation of

shore features. It was afterward announced by Dr. Spencer that he had succeeded in tracing the shore line several miles farther eastward than I had seen it, and this announcement stimulated me to renew my search. In the autumn of 1890 I revisited the region in company with Mr. Warren Upham. Starting at Adams Centre, we ran a line of levels past Watertown to cape Rutland, a point where the shore features are clearly exhibited at the western margin of the sand plain. This point, which had previously been missed by me, was discovered by Dr. Spencer. The shore-line there has an altitude of 730 feet. Thence we carried our level line to the eastern margin of the sand plain, where we found a rock surface thinly covered with drift and well adapted to the preservation of a shore record. Over this surface we made search through a range of altitudes extending 50 feet below the horizon, where shore features were to be expected, and an equal distance above. Our results were purely negative. The drift seemed not to have been disturbed by the waves.

About the same time Dr. Spencer also returned to the field and carried his observations farther eastward and to higher levels. The results he communicated to me* accorded so poorly with mine that I proposed a joint excursion, hoping that if we saw the phenomena together we might come to view them in the same way. The hope was not realized, but our journey was nevertheless fruitful. It served to prove that we differ widely as to the criteria by which shore ridges and shore terraces are distinguished from ridges and terraces of other origin. In the series of localities to which Dr. Spencer conducted me, from Natural Bridge to Fine, I saw but a single ridge that seemed to me to simulate a shore ridge, and the associated phenomena made me confident that that was a case of simulation only. Instead of a shore-line or group of shore-lines I saw a magnificent series of kames and pitted plains, occupying the valleys of a rugged district, and associated with channels of temporary discharge from one valley to another. The series is too complex to be analyzed fully during a rapid reconnoissance, but all its elements announce the margin of an ice field, and none of them announce the margin of a lake. I am still of opinion that the Iroquois shore-line ends at cape Rutland, and that the Iroquois water was bounded on the northeast by a wall of ice on which the waves could make no permanent record.

A few words as to Dr. Spencer's second paper: The channel features at the col have greater extent than he mentioned. The rock floor is swept clear of all drift except a few bowlders of great size. North of the col one passes from the rock floor to the gravel terrace of the Black river valley without notable change of altitude. South of the col one descends toward the Mohawk for two miles or more before he finds the rock floor covered by drift or alluvium. The vertical descent in this distance is not less than 60 feet. These features appear to accord with the theory that a river descended southward from the col far better than with the theory that the col was swept clean by tidal currents.

It is true that there are terraces south of the col accordant in height with the great terrace north of it, but the assumption that these are shore terraces is gratuitous. Terraces originate in many ways, and it is not always easy to determine the origin of individual examples. The terrace on which Dr. Spencer bases his argument was not well displayed nor was it carefully examined. I noted no feature

* These results are briefly mentioned also in Am. Journ. Sci., 3d series, vol. xl, 1890, pp. 443-448.

which can be regarded as diagnostic. Some of the lower terraces south of the col—those indicated by the aneroid as at 970 and 940 feet above tide—have peculiar features indicating that they are not littoral. Though resting on a steep slope, they are characterized by well rounded bowlders of large size, from one to three feet in diameter. Under wave action such material would be rolled down the slope. Moreover, each of these terraces is margined toward the valley by a parapet of the same material. The parapet is low, not more than one or two feet high, but it suffices to control the drainage of the terraces. These features suggest that an ice tongue once occupied the bottom of the valley, and that a torrent coursed between the ice margin and the valley wall. Our brief visit afforded no time to test this explanation and I do not offer it with confidence; but its suggestion will illustrate to the Society the danger of the assumption that all high lying terraces record levels of standing water.

Mr. I. C. Russell remarked:

Recently it has been my fortune to observe in association with Alaskan glaciers certain terraces with marginal parapets which were formed in the manner suggested by Mr. Gilbert, *i. e.*, by streams following the lateral edges of glaciers.

Dr. Spencer replied:

I have shown in my various papers preceding this that the deformation which lifted the beaches in the lake region was principally produced after the Iroquois episode, and that the 350 to 400 feet of eastward elevation between the head of lake Michigan and the eastern end of lake Erie affected the whole Iroquois plain and lifted the old shore line at the head of lake Ontario to 363 feet above the sea, as we see it to-day. Hence it seems to me to be a defiance of observations to regard the Iroquois shore as having been formed above sea-level, as has been also frequently stated by Mr. Upham, although Mr. Upham now extends the Iroquois water to the vicinity of Quebec.

That the region north of the Adirondacks may have been a sea filled with icebergs or even a glacier is not considered here, but only that the Iroquois water-plain continued at least 100 miles northeast of Watertown—a theory supported throughout this very broken region (a former archipelago) by delta and terrace deposits at the mouth of every river at elevations corresponding to the deformation measured in the vicinity of Watertown. In composition and physical structure the appearance is close, there being no other deposits liable to misidentification. Throughout this region there are other than the delta and terrace deposits at the mouths of all the old valleys corresponding to the Iroquois plain; but even though such deposits may be christened "kames" and "pitted plains" by glacialists, their uniform glacial origin has not been so demonstrated by actual connection with modern glaciers that their occurrence is *ex cathedra* evidence of glacial dams. It is not doubtfully located deposits upon which I based my criteria, but the recurring delta and terrace deposits at the river mouths; hence the grounds which make my distinguished critic and myself "differ radically as to the criteria by which shore ridges and shore terraces are distinguished" from glacial levels; nor can I gerrymander glaciers into the region to account for the chains of phenomena which are regarded as characteristic of the Iroquois water-level; but it is unsafe to theoretically throw glacial dams across beach deposits.

Mr. Gilbert's suggestion, in connection with the second paper,—that the valley south of the divide was filled with ice, and that the terrace, 200 feet below the highest, indicates the coursing of a river between the ice and the side of the valley, eroding the drift-floor and forming a parapet only one or two feet high,—should be placed alongside of the explanation of the cleaning out of all the drift from the summit of the col, where the current must have been more sluggish, by a glacial river. The object of this paper is only to point out a conspicuous example where terraces do occur upon the southern sides of the valley divides, in regions of reputed glacial lakes, and therefore the absence of the terraces upon the southern sides of divides must be proved and not simply asserted.

President Gilbert resumed the chair, and the following paper, the illustrations of which had been exhibited the preceding evening, was then read:

THE GEOLOGY OF THE CRAZY MOUNTAINS, MONTANA.

BY J. E. WOLFF.

Remarks were offered by J. S. Diller, G. K. Gilbert, B. K. Emerson and Arthur Winslow.

The paper is printed as pages 445–452 of this volume.

This was followed by—

NOTES ON THE GEOLOGY OF THE YUKON BASIN.

BY C. WILLARD HAYES.

[*Abstract.*]

During the summer of 1891 the writer was detailed by the Director of the United States Geological Survey to accompany Lieutenant Frederick Schwatka on an expedition designed to explore the southern portion of the Yukon basin, Alaska. The route followed was by way of Taku river, lake Ahklen, and Teslin and Lewes rivers to the confluence of the Lewes and Pelly, which form the Yukon; thence southwestward through the basin of White river, across the interior range of the Saint Elias mountains by a pass at the head of White river, and down Chittenah and Copper rivers to the coast. The distance traveled was about 1,000 miles, over 700 being through unexplored country. The principal geographic results of the expedition are the approximate mapping of Taku river, lake Ahklen and Teslin river; also of a large part of the basin of White river, and portions of the Saint Elias mountains. Systematic observations on the hard geology were rendered impracticable by the difficulties attending travel in the region traversed. The rocks along White river basin are chiefly eruptives, with a few highly altered sediments of undetermined age. The interior range of the Saint Elias mountains extending northwestward toward mount Wrangell has a simple synclinal structure and is composed chiefly of Carboniferous and Triassic strata. The white volcanic tuff which has been noted by various travelers on the Lewes and Pelly was found to increase gradually toward the west, reaching a maximum of from 50 to 75 feet in thickness in the upper White river valley, from that point decreasing very rapidly westward. The probable source of the tuff is a high conical peak in the northern

border of the Saint Elias mountains and just west of the 141st meridian. Several glaciers were found flowing northward, but the ice drainage in that direction is small compared with that southward from the same mountains, and the lower limit of the névé fields is over 4,000 feet higher on the northern than on the southern side of the range. The northern limit of glaciation in the White river basin is only about forty miles north of the present termination of existing glaciers, and the greater part of the basin appears never to have been covered by an ice sheet.

The substance of this paper will be found in the National Geographic Magazine, volume iv, 1892, pages 117–152, with plates 18–20, under the title "An Expedition through the Yukon District."

The next communication was entitled:

GEOLOGY OF THE PRIBILOF ISLANDS.

BY JOSEPH STANLEY-BROWN.

On the chart of Bering sea and the Arctic ocean issued by the Hydrographic Bureau for 1889 are compiled the soundings made in those waters up to that date. It requires but a glance at this chart to make plain the fact that Bering sea is in large part an extremely shallow body of water. An elevation of 300 or 400 feet would convert most of the present sea bottom into a vast verdure-covered tundra, whose gently undulating surface would be dotted with lakes and intersected by sluggish winding streams. Upon such a land surface the four tiny islets to which this brief sketch refers would appear as conspicuous elevations.

In the waters of this shallow sea in very recent geologic time were created the Pribilof or Seal islands.* Their formation was a simple process, and its successive steps are recorded with unusual legibility.

In offering the results of a study † of this little geologic unit, the facts upon which conclusions are based will be given only when clearness demands their presentation.

The islands owe their origin to vulcanism. The geologic agents still busily engaged in modifying them are the surf that beats ceaselessly upon their shores; the ice which surrounds them in winter; the drifting sands; and the luxuriant wild grasses and other herbage. Precipitation, though generous, is rarely violent, and erosion plays an insignificant rôle.

Saint Paul island, the largest member of the group, is 12 miles long and from 6 to 8 miles wide. Its surface is diversified by at least a dozen cones and vents of unusual symmetry, surrounding in irregular fashion a true crater some 600 feet in height, called Bogoslof. The shores are lowlying, and sea-cliffs of conspicuous height are infrequent.

After the initial establishment of an outlet for the molton material, free from the intrusion of the sea, there were four well marked episodes in the career of the island. From this central point, that probably finally became the present Bogoslof, there welled out great masses of lava which made their way outward in all direc-

* The Pribilof islands are in latitude 57° north, longitude 170° west from Greenwich, and are about 200 miles northwest of Unimak pass, one of the natural waterways of the Aleutian chain through which vessels find their way into Bering sea.

† Opportunity for this study was had in the summer of 1891, while the writer was acting temporarily as an agent of the Treasury Department for the investigation of the condition of seal life on the islands.

tions until overcome by the cooling waters of the ocean. This flow of highly vesicular basalt, rich in olivine, can be seen at many points on the shore. It forms the floor of the island, and where not covered by overlying material its tongue-like prolongations make reefs dangerous to navigation. Upon this basaltic pavement were built up meanwhile the vents and cones, which now stand as perfect as on the day of their completion.

The third step in the process of construction was a second discharge of lava from the central crater, aided by feebler outpours from the vents which surround it. This constitutes the overlying sheet. It is readily distinguished macroscopically from the basement lava; it is identical with it in mineralogic composition, but it is more highly crystalline, and structurally it is puniceous or spongy in texture rather than vesicular. The contact of the two sheets is clearly marked and is invariably near the water level. This latter fact is not due to wave action, for the markings of flowing lava remain on the basement surface at the line of contact. In this upbuilding process perfectly arched volcanic tunnels with thin domes were formed by the molten streams, while over the surface of the flow many jets of lava were cooled and fractured into natural cairns so like the artificial monuments or "miaks" made by the natives as to be readily mistaken for them. It would be difficult to find more trustworthy registers of orographic changes than these tall, tapering cairns.

The central portion of the island is today just as it was created: The lavas lie unchanged in form and unaltered in their mineralogic constituents; no general shifting of level has occurred to disturb the uprightness of the slender miaks, to break down the fragile domes of the volcanic tunnels, or to interfere with the horizontality of the basement lava. On the southern shore an old sea beach of rounded pebbles and bowlders made of fragments of the floor basalt now stands 25 or 30 feet above the sea level, but the area involved would be represented only by a circle a quarter of a mile across The disturbance was local and due to the formation of a small cone, only a few vestiges of which have been left by the sea. No glaciation has smoothed away the cairns, carved the surfaces of the huge basaltic blocks, or rounded their jagged edges. The cones and vents, which often bear tiny lakelets in the cup-shaped depressions on their summits, stand unimpaired in their symmetry. In no place has erosion left a scar. No erratics are found on the higher levels, except such pebbles as were brought by a novel geologic agent—the stomachs of seals and sea lions.

Every scrap of physical and petrographic evidence indicates the recency of the island's formation, and a sea-dissected cone, known as Black bluff, on its eastern side furnishes additional testimony. Distributed through this cliff of basaltic tuff are rounded calcareous clay fragments, bearing fossil shells.* Extinct forms of

* It is stated by Elliott in "Our Arctic Province" (p 229) that in Black bluff occur "stratified horizontal lines of light-gray calcareous conglomerate or cement, in which are embedded sundry fossils characteristic of and belonging to the Tertiary age, such as *Cardium grœnlandicum*, *C. decoratum*, and *Astarte pectunculata*, etc." It is true that the general appearance of the cliff would indicate such a state of affairs, but when the structural details are closely studied it is found that while the cliff has a somewhat stratified appearance that might have been due to a puddling of the cinders and ashes of which it is composed, the fossils are confined to a clay rock which occurs in much rounded fragments from a few inches to two feet in diameter. These are scattered with some irregularity and not copiously through the mass, and are in all stages of decomposition incident to the agency of heat and moisture. The evidence would appear to be conclusive that these fragments were caught up mechanically from the adjacent sea bottom and distributed through the cone during its creation.

mollusks have been found there, but of the fifteen species brought back by me this past summer and identified by Dr. Wm. H. Dall,* all have living representatives in Bering sea.

When the three constructive episodes were ended, then began a period of destruction and rearrangement of material about the margin of the island. Here the waves converted the lavas and tuffs into bowlders, pebbles and sand, and distributed them along the shores in characteristic forms; the ice crowded the coarser material inland, forming ramparts invulnerable to the assaults of the sea; over this in turn the sand was scattered, and not only were the margins thus extended, but the lowlying lava flows were built upon and the newly formed areas firmly joined to the mainland. The winds caught up the sands and built them into dunes, which continuously encroach upon the sea and which are made constant by the long roots of the wild grasses that ever grow upward as more sand is added. To these processes are due about one-fifth of the area of Saint Paul, and such topographic features as the lagoon, the ponds along the shores, and the lakes at Northeast point. This work of construction continues and will probably keep pace with the destruction of the island.

About 36 miles southeast of Saint Paul lies Saint George, an island a little smaller than its companion and very different topographically; but few cones dot its surface; accessible shores are exceptional; and instead of lowlying sea margins, bold precipitous bluffs from 300 to 900 feet high are the rule—the island stands like a mesa on a watery plain. While the story of its formation is in the main that of its neighbor, there is another factor involved, that of orographic movement. There is a floor of dark vesicular basalt, but the point of the first outpour is not well defined. From Oolakaiyá, the name given to the remains of a vent near the middle of the island and now over 900 feet high, came the bulk of the succeeding flows. Indeed the extravasation from this center, aided perhaps by outflow from other vents to the northeastward, built up the entire eastern half of the island. This main vent also contributed a sheet to the westward, which was augmented by material from a great cone on the northern shore. This cone has been more than half eaten away by the sea and now forms High bluff, a perpendicular tuff cliff of nearly 1,000 feet.

---

* Dr. Dall's report is as follows:

"*Washington, D. C., November* 13, 1891.

Dear Mr. Stanley-Brown:

The fossils from Black bluff, Saint Paul island, Bering sea, are, so far as determinable, of recent species still living in the same region, though other collectors have obtained at the same locality specimens of extinct forms. Beside remains of an ophiuran starfish and the tube of a worm, like that made by *Sabella*, there are remains of fifteen species of mollusks below enumerated. The figures in brackets following the name indicate the number of times the species occurred in the collection, and thus their relative abundance.

* *Buccinum tenue*, Gray ? [3]
* *Buccinum polare*, Gray ? [1]
* *Admete couthouyi*, Say ? [1]
Natica clausa, B. and S. [4]
Modiolaria nigra, Gray [10]
Nucula, sp., perhaps *N. tenuis* [1]
* *Leda*, sp. [1]
* *Yoldia limatula*, Say [1]
* *Lepton grande*, Dall [2]
Cardium grœnlandicum, Gmel. [18]
?* " *islandicum*, L. (*decoratum*, Grew.?) [15]
Tellina (*Angulus*), sp. [1]
* *Macoma* (*sabulosa*, Spgl. ?) [1]
Kennerlyia grandis, Dall [1]
Saxicava arctica [11]
* *Panopea*, sp. ? fragment, possibly a *Saxicava*.

The species marked with an "*" have not been reported from this locality before.

Yours very truly,

Wm. H. Dall,
Paleontologist, U. S. Geological Survey."

An uplift then gave to most of the island an additional elevation of 200 or 300 feet, accentuated the ridges formed by the outpours, gave them a monoclinal aspect by converting their northwesterly faces into bluffs as steep as they could be made by great blocks of broken lava, and formed shallow troughs between them and the shores. The parallelism of the faults is well displayed to any one standing on the summit of the central vent.

With two exceptions the lavas of the islands are basalts identical with those of Saint Paul, save in the alteration of their olivine. The decomposition of the olivine is in all stages of advancement, accompanied by the formation of red oxide of iron. Otherwise it would be impossible to distinguish these lavas, microscopically, from the rocks of Saint Paul.

On the northern shore of the island, at a point just east of the village, a basaltic dike from 2 to 3 feet in thickness and parallel to the ridges, cuts through the tuff, which here overlies and rests immediately upon the floor lava. This dike, though a true basalt, differs from the adjacent rock in that it contains enstatite in addition to the usual augite. Just opposite this dike, at Garden cove on the southern shore, Mr. Elliott* states that he noted a "large dike of bluish or greenish-gray phonolite, in which numerous small crystals of spinel are found." Unfortunately this dike could not be discovered by me on my visits to Garden cove, but there is at that locality a large mass of compact greenish-gray peridotite, which dips northeastward at about 45°, and upon the upturned edges of which rest, unconformably, the overlying lavas. The area of this mass and its relation to the other material cannot be entirely made out. The peridotite is composed of enstatite and olivine, and serpentinization is well advanced.

At the only two points on the island where the shores are lowlying, the floor of dark vesicular lava is horizontal and near the level of the water. This may not in all cases be due to wave action. Outlying reefs are rare, and the water surrounding the island is, as mariners say, "bold." The earlier constructional forms are nearly obliterated; no true crater remains intact; and hence the cup-shaped depressions at the summits of the cones and vents of Saint Paul are here lacking. No natural cairns or volcanic tunnels are to be seen, and the surface lavas along the ridges often have the form of plates, of all degrees of thinness, that ring like porcelain when trod upon. There are no marks of glaciation or of erosion, and no erratics occur. Disintegration is apparently the only process now going on.

There remain two other tiny members of the group, Otter and Walrus islands, each about 6 miles off the shores of Saint Paul; but their geologic story is so similar to, and so identified with, that of their greater neighbor that, for the sake of brevity, its recital is omitted.

There are two fragments of paleontologic evidence connected with the islands which, as they have been used by writers, demand a cautionary word. The tusk of a mammoth was found in the sands of Northeast point on Saint Paul island, and the tooth of one is reported as coming from the shores of Saint George. As there is not a foot of earth upon either island, save that which has resulted from the decomposition of the native rock and the decay of vegetation, the value of such testimony is questionable.

Small as the Pribilofs are, they afford ground for differences of opinion. In writing of these islands, Mr. John Muir† has said that they "appear in general

*"Our Arctic Province," p. 227.

†"Arctic Cruise of the Revenue Cutter 'Corwin,' 1881: Notes and Observations," p. 140.

views from the sea as mere storm-beaten remnants of a once continuous land, wasted into bluffs around their shores by the action of the waves, and all their upper surfaces planed down by a heavy oversweeping ice sheet and slightly roughened here and there with low ridges and hillocks that alternate with shallow valleys. None of these features, so far as I [he] could discover, without opportunity for close observation, showed any traces of local glaciation or of volcanic action subsequent to the period of universal glaciation."

It is hardly necessary to state that this view of the islands does not accord with my brief résumé of their origin and career.

Told in a sentence or two, the history of the Pribilof islands is this: In post-Pliocene time they were formed by successive outflows of basaltic material; Saint Paul and its two tiny companions remain as created, save where destructive and constructive agencies have been and still are at work on the shore margins; after its creation by a similar volcanic process, Saint George was modified by orographic movement that revealed a portion of the sea floor, and then began the work of annihilation which has since continued.

The tendency of the evidence gathered is toward a synchronous creation of all the islands of the group, but no indisputable facts upon which to base a conclusive argument could be obtained.

The last paper of the day was on—

SOME NEW FOSSIL FISHES FROM THE CLEVELAND SHALE.

BY E. W. CLAYPOLE AND W. CLARK.

The fossils were exhibited and discussed.

The following invitation was announced:

The Fellows of the Geological Society of America are invited, on the part of some of the colleagues of Dr. Orton in the Ohio State University, to lunch at the Columbus Club to-morrow, Thursday, at 12.30 p. m.

Announcement was again made of the dinner at the Neil House in the evening, and the Society adjourned for the day.

Session of Thursday, December 31.

A letter was read from Professor Edward Orton, in reply to the resolution of Wednesday morning, as follows:

Columbus, Ohio, Dec. 30, 1891.

Professor H. L. Fairchild,
Secretary Geological Society,
Columbus, Ohio.

My Dear Sir:

I am deeply sensible of the kindly feelings of the Geological Society of America as expressed in the resolutions touching my present disability, which were for-

warded to me this day, and I desire you to convey to the Society my grateful appreciation of its sympathy and good wishes.

I regret more than I can tell you my inability to add anything whatever to the pleasure or profit of the Columbus meeting, to which I have been looking forward with high expectations for the last six months.

I rejoice with you in every addition that is being made to our knowledge of American geology. I count it a great honor and privilege to have been able to contribute even in the humblest degree to its advancement, but no one realizes more distinctly than I do at this time how small a part the contributions of even the most gifted member of our profession make to the wide and ever widening river of our knowledge. I am sure that we all recognize the fact that our work so far is mainly limited to the headsprings of the river.

I close with the sentiment, "The Geological Society of America, *esto perpetua*."

Very truly yours, EDWARD ORTON.

The first paper read was entitled:

THE GULF OF MEXICO AS A MEASURE OF ISOSTASY.

BY W J MCGEE.

[*Abstract.*]

The term "isostasy" was coined by Dutton to denote a condition of static equilibrium in the terrestrial crust, in virtue of which areas of degradation rise and areas of deposition sink. The earlier data on which the doctrine of isostasy depends were *indirect*, *i. e.*, they were inferences from ancient formations and old surfaces; but it is now found that the modern continental movements affecting areas of deposition yield *direct* data sustaining the doctrine. Such data may be either *quantitative*, when the rate of movement is measured, or *qualitative*, when movement is ascertained but not measured. The most trustworthy measured examples are (1) the Netherland coast, which has been under observation for a millenium and which is subsiding beneath the sediments of the Rhine and its neighbors at a rate varying from 0.09 to 0.75 meter per century, the mean since 1732 being 0.26 meter; and (2) the New Jersey coast, which is subsiding beneath the sediments of the Hudson and Delaware at the rate of about two feet per century. Scarcely less decisive evidence of subsidence, though at unmeasured rates, is yielded by every noteworthy deposition tract of the globe (exclusive of Africa, where the data are inadequate), including the embouchures of the Amazon, the Yang-tse-kiang, Hwang-ho, la Plata, the European rivers embouching into the Black and Azof seas, the Volga and Ural, the Syr Daria and Amu Daria (together feeding the Aral sea), the Ganges and Bramaputra, the "Five Rivers" headed by the Indus, the Saint Lawrence, the Po and its neighbors, and the Mississippi. On reviewing this evidence it appears that every considerable deposition tract beyond the reach of Pleistocene glaciation, vulcanism and orogeny is subsiding; that, other things equal and so far as the data are available and reliable, the rate of subsidence is proportional to the relative areas of degradation and deposition; and that, other things equal and so far as the data are available and reliable, the subsidence is proportional to the activity of the rivers in the correlative degradation tracts. So the direct data con-

cerning isostasy derived from the geologic record are supplemented by a trustworthy body of direct data derived from the physiography of the earth in its present condition; and the direct data are superior to most of the indirect in that they are susceptible of relative, and in some instances positive, evaluation.

The Gulf of Mexico is one of the most fortunately situated deposition tracts of the globe for the measurement of isostatic subsidence in that it is a nearly closed land-rimmed basin of considerable area fed by drainage from a many times larger degradation tract; and, moreover, the sedimentation is not confined to a single delta, but is distributed in simple and easily ascertained fashion. Now, the Gulf coast has only recently been surveyed with precision, and the surveys have not been repeated in such way as to give quantitative rate measurements of movement; but the physiographic evidence of subsidence is unmistakable and indicates a mean rate not less, and probably more, than a foot per century. This rate is somewhat less than the estimated degradational transfer of material requires. Moreover, the physiographic indications of subsidence vary in strength about different parts of the coast; they are weakest in the northeast, where the affluents are short and feeble; stronger in the northwest, where the affluents are longer and more potent; strongest in the north about the delta of the chief river of the continent. In brief, if the Gulf of Mexico be considered as a unit, its shores appear to be subsiding about as rapidly as isostasy demands; and considered as an assemblage of deposition tracts, the local rates of subsidence appear to be delicately adjusted to the local rates of deposition. Accordingly, the data yielded by this fortunately situated deposition tract indicate that throughout the vast geologic province of southeastern North America isostasy is probably perfect, *i. e.*, that land and sea bottom are here in a state of hydrostatic equilibrium so delicately adjusted that any transfer of load produces a precisely equivalent deformation.

It is well known that the later formations of the Gulf province (notably the Columbia and Lafayette formations) represent continental oscillations reaching several hundred feet in amplitude. Now in contrasting these great oscillations with the gentle modern movement of the coast, they are found to differ widely; the modern subsidence is a gentle warping in such direction as to deepen the basin and gradually submerge its perimeter, while the old oscillations were wide-spread and involved both sea-bottom and continent; the modern movement is slight and commensurate with the simple and uniform processes of erosion and sedimentation, while the old movements were cataclysmic and utterly transcended the influence of rain and rivers. Accordingly, while the modern movements give a better measure than has been obtained elsewhere of the efficiency of degradational transfer of matter as a cause of deformation, the movements recorded in the Columbia and Lafayette formations were of so much greater amplitude that they may not be referred to a similar cause; therefore in this province, as in others, it becomes necessary to discriminate the two classes of earth movements elsewhere called respectively *antecedent* and *consequent*. So the modern province measures the competence of isostasy, the ancient province its incompetence; the modern Gulf illustrates the magnitude, the ancient Gulf the minitude of isostatic deformation as a means of continent-making.

Although isostatic action alone is incompetent to explain the great continental oscillations attending the deposition and degradation of the Columbia and Lafayette formations, certain peculiarities in these oscillations may be hypothetically explained through the doctrine of isostasy. During the low-level periods represented by the

deposition of the Columbia and Lafayette formations and during the high-level periods represented by the degradation of both these formations, the continent was warped in curiously consistent fashion; during both low-level periods there was an axis of maximum subsidence approximately marked by the cities of Charleston and Memphis and an axis of minimum subsidence approximately marked by cape Hatteras; and during both high-level periods the Charleston-Memphis axis was one of maximum uplift, and the Hatteras axis one of minimum uplift—*i. e.*, the former axis was one of maximum and the latter of minimum movement throughout the oscillations. Now, this warping is so related to the varying configuration and unequal density of the southeastern portion of the continent as to suggest that it was produced by changes in stresses growing out of the varying degrees of submergence. If the hypothesis be established, the efficiency of isostatic action will become so extended as to demand recognition among the more important, though always secondary (or consequent), agencies of mountain-building and continent-lifting.*

A spirited discussion followed the reading of the paper, participated in by G. K. Gilbert, E. W. Claypole, I. C. White and the author. Professor White remarked:

My studies of the valleys of certain rivers in the Appalachian region have led to similar conclusions concerning the susceptibility of the terrestrial crust to changing loads. Several instances of warping apparently caused by subsidence due to loading have come to my knowledge, the North Susquehanna valley between Pittston and Bloomsburg being a conspicuous example.

Mr. Gilbert said:

The communication is an important contribution to the subject, in that it recognizes the limitations of isostatic action. The phenomena of orogeny and epeirogeny are too complex for complete explanation by the single cause of loading and unloading, which are really conservative processes; and research concerning the primary causes is facilitated by definition of those of secondary character.

Professor Claypole remarked:

While forced to express admiration for the exhaustive, able and eloquent statement just presented, I am impelled also to point out certain objections to the theory that given areas sink because of loading, while contiguous areas rise because of unloading. If the theory were true, the coördinated process would tend to keep rivers and other geographic features indefinitely in their places, while in reality they are constantly shifting. It seems to me that under this theory the true order of the processes is reversed; that in point of fact areas of deposition become such by reason of subsidence, and that contiguous areas are degraded because of elevation. Again, it seems to me that the argument proves too much—that the subsidence of the Netherland and New Jersey coasts is too great to be produced by the relatively slight deposition now taking place on the sea bottoms. On the other hand, the theory fails to account for the origin of such great features of the earth's surface as the Gulf of Mexico and the Rocky mountains; so that some more general forces would seem to be required to explain the movements of continents and sea bottoms. A theory that needs to be eked out with another seems superfluous. Moreover,

*The greater part of the paper is printed in full in the Am. Journ. Sci., vol. xliv, pp. 177–192, 1892.

the argument that the subsidence advances in proportion to the load imposed is untenable, because, whatever the amount of depression may be, the cavity will be filled if sediment be sufficiently abundant and cannot be more than filled under any conditions. In many known cases also subsidence has ceased just when the load was greatest, the cavity being full.

Professor Emerson said:

The communication bears on the question as to whether the Pleistocene submergence of many northern lands was due to the weight of ice-sheets laid down over these lands, and would seem to give an affirmative answer, except that it fails to explain why the sinking lagged so long behind the loading.

Mr. McGee rejoined:

A principal purpose of the paper is to define the limitations of isostatic action and to show that this cause is incompetent to produce the grander features of the earth's surface exemplified by the Rocky mountains, the Gulf of Mexico and other continents and seas—*i. e.*, features due to the movements classed as antecedent,—yet that it is competent to produce such minor warping of the terrestrial crust as that displayed by the present shores of the Gulf of Mexico and by ancient formations in many parts of the world. The fact of subsidence at a rate proportioned to the length and activity of the tributary rivers in every important deposition tract of the globe cannot be gainsaid, and to me it is absurd to hold that the length of the Mississippi or the Amazon or the Indus is determined by the rate at which its delta is sinking. The Netherland and New Jersey coasts are indeed subsiding rapidly; yet it is to be remembered that by reason of geographic conditions, including not only the configuration of coasts but the action of tides and currents, sedimentation is in both cases confined to areas far smaller than those of degradation. The theory of isostacy indeed makes for the doctrine of the persistency of rivers and even of continents and oceans, but no more strongly than the facts of geology. Rivers are the most persistent features of the earth, and the tendency of recent research is to indicate the long, though not endless, persistence of the grander geographic features.

The second paper of the day was on—

PRE-GLACIAL DRAINAGE OF SUMMIT COUNTY, OHIO.

BY E. W. CLAYPOLE.

Remarks were offered by W. H. Sherzer, G. F. Wright and G. K. Gilbert.

The following papers were next read:

OBSERVATIONS RELATING TO THE FORMATION OF LAKE GENEVA, SWITZERLAND.

BY G. FREDERICK WRIGHT.

The paper was illustrated by charts and diagrams.

SUPPOSED INTERGLACIAL SHELL-BEDS IN SHROPSHIRE, ENGLAND.

BY G. FREDERICK WRIGHT.

Much light has recently been shed upon the condition of the British isles during the glacial period. The ice which covered so large a portion of them proceeded from four grand centers.

(1) The first center was Scandinavia. After having moved across the shallow bed of North sea, the ice from this center reached the eastern coast of England from Flamboro head to Yarmouth, and advanced westward to a line connecting Flamboro with London, covering Holderness and a considerable portion of Lincoln, Cambridge, Norfolk and Suffolk counties. The western limit, however, was quite irregular; but Scandinavian bowlders are definitely recognized at various places along the coast and in the interior. North of Bridlington, Scandinavian ice was prevented from reaching the coast by the glacier-shed eastward from Scotland and the northern uplands of England, which partly preoccupied the ground.

(2) The mountain plateau in northern Wales, of which Arenig, Mawr and Snowdon are the culminating points, was a second center from which ice advanced into England, moving eastward as far as Birmingham, a distance of about 100 miles. This is evidenced by an interesting line of bowlders extending nearly north and south, or nearly at right angles to the movement of the great Welsh glacier. This line of bowlders extends from the vicinity of Litchfield through Birmingham and southward to Bromsgrove. Not only are most of these bowlders definitely traceable to the Welsh mountains, but near Litchfield some have been found which were brought from the Wrekin, the remnants of a Silurian mountain near Wellington in Shropshire, and about one-third of the distance between Litchfield and Arenig.

Until quite recently it has been a puzzling circumstance that the glacial deposits of western Staffordshire and northern Shropshire were characterized not by Welsh bowlders but by bowlders that can be clearly traced to the Lake district in England and to the southwestern portion of Scotland. Shap granite from Westmoreland and granite from the Criffel mountains north of Solway firth abound in great numbers in the till of this area. It is in the glacial deposits at Ketley, near Wellington, that Mr. Prentiss Baldwin and myself succeeded in finding the shell-bed from which the accompanying specimens were obtained. As identified for me by Professor Albert A. Wright, the shells are as follows:

Nassa reticulata; one specimen. Common in England and France; also fossil from the Miocene throughout Europe.

Turritella (*Communis?*); many specimens. Smaller than the average but similar in sculpture (Britain has only one species of *Turritella*, viz, *Communis*).

Dentalium; one specimen (tubular).

Lucina?; one valve.

Fragments of ribbed *Cardita* (possibly *Cardium*).

These specimens were near together in a gravelly stratum two or three inches thick, which was underlain by a sandy deposit 25 or 30 feet thick and overlain by from 10 to 15 feet of true till, containing scratched pebbles and small bowlders in abundance, the bowlders being all either from the Lake district or from southern Scotland. The pit in which this section was shown has been extensively worked

to obtain the underlying sand, but nowhere did we see the stratum upon which the sand rested, so that we were unable to speak from observation of its nature; but from the distribution of Welsh bowlders in the vicinity of Birmingham already mentioned it is absolutely certain that Welsh ice had moved over this area previous to the invasion of glaciers which started from southern Scotland. They are therefore without doubt what would properly be called interglacial beds. Their elevation above the sea, as given me by Dr. Crosskey and Mr. F. W. Martin, who accompanied us on the trip and conducted us to the locality, is in round numbers 500 feet. The Wrekin, two or three miles away, is a solitary peak in the Severn valley, rising 1,335 feet above the sea. In other localities of the vicinity Dr. Crosskey had found shells having a more arctic character than these in glacial deposits of similar character about 700 feet above the sea.

In endeavoring to account for these shell-beds it will be necessary to take a still more general view of the situation, and it is the more important to do this since the explanation of this deposit is doubtless closely connected with that of similar deposits found at still higher levels, namely, at an elevation of about 1,100 feet at Macclesfield, a few miles south of Manchester, and at 1,400 feet near Moel Tryfaen, on the northwestern flank of Snowdon in Wales. On glancing at an orographic map of England, it appears that between the northern part of the Welsh highlands and the southern projection of the Pennine chain in England there intervenes a valley, about 70 miles wide, known as the vale of Chester, running nearly north and south, which is nowhere more than 500 feet above the sea. The shell-beds under consideration occur near the head of the Severn valley at just about the same height as the water-parting between the valleys of the Severn and the Dee. A careful collection of facts made by Professor Percy F. Kendall concerning the distribution of Lake district and Scottish bowlders makes it clear that the vale of Chester was occupied by the eastern branch of a confluent glacier which filled the Irish sea, receiving vast contributions of ice from the two remaining centers of glacial dispersion referred to above, namely, (3) the southwestern portion of Scotland and northern England, and (4) Ireland.

Bowlders from the Lake district in England moved westward into Morecambe bay, where they were met by the movement from Scotland; while in the meantime glaciers from Ireland pushed eastward into the Irish sea until the whole basin north of Wales was at length filled with ice under sufficient head to abut against the Welsh mountains and to push upward upon their northern flanks to a height of more than 1,400 feet. But the main mass of ice was divided by the obstruction and flowed in two streams, the one over Anglesea on the west into Saint George channel to an indefinite distance, the other on the east through the vale of Chester almost to Birmingham, occupying the area already described as covered by bowlders from northern England, and Scotland. It was this movement which deposited the till at Ketley and which, I believe, brought along from the bottom of the Irish sea the shells which were there found by Mr. Baldwin. This is the theory advocated by the late Professor Henry Carvill Lewis to account for the shell deposits found at Macclesfield and Moel Tryfaen.

The considerations supporting this view are numerous: First, such shell-beds in glacial deposits are strictly confined to areas known to have been occupied by glacial ice which had previously moved over shallow sea-bottoms. At Ketley the bowlders in the upper till all came from southwestern Scotland or the Lake district in England by way of the Irish sea. Similar shell-beds found in the glacial deposits of

eastern England are confined to the area invaded by Scandinavian ice which moved across the North sea bottom; and between Flamboro head and Bridlington there is very clear evidence that portions of the old sea-bottom were pushed up by the ice to a height of nearly 300 feet. Such an instance was pointed out to me by Mr. Lamplugh in the till overlying the chalk bluffs near Flamboro. Here it was clear that a mass of clay, including shells, had been pushed along and drawn out by the differential motion, and in some cases shells were found in the clay with the concave side down, but filled with sand, which had served to make it a compact mass capable of moving like any other pebble. These actual instances observed by Mr. Lamplugh go very far to remove the antecedent objections which every one would at first naturally urge to the theory. It should be noted also that the till at Moel Tryfaen, at Macclesfield and at Ketley, as well as on the eastern coast of England, contains numerous fragments of shells of the species found in the shell-beds. It is easy to see, therefore, how they could be collected into thin beds by local currents of water that must have arisen in connection with the melting of the glacial ice which we know to have covered the locality where they were found.

Secondly, the shells in most of these beds do not represent any definite fauna. The forms associated represent those living in cold water side by side with those living in warm water, and rock-haunting species with sand or mud loving species. On the Isle of Man, Professor Kendall has found in the glacial drift of the northern shore representatives of *Nassa serrata*, Brocchi, a mollusk which is now characteristic of the Mediterranean sea and cannot endure even the present temperate climate of the Irish channel. It certainly could not have endured the rigors of a glacial climate, even with the supposed amelioration during the so-called interglacial epoch. The species, however, lived in the Irish sea during the Pliocene period. On the theory that the shells were pushed up from the bottom of the sea by the advancing ice, this and all similar cases are readily accounted for.

Thirdly, outside of the area in England which was not reached by glacial drift there is a noteworthy absence of all the signs of submergence. "There are no true sea beaches, no cliffs or sea-worn caves, no barnacle-encrusted rocks or rocks bored by *Pholas* or *Saxicava*." Nor are any shells found in post-Tertiary deposits anywhere except in the area covered by ice which is known to have moved over a sea-bottom. This is incredible if the subsidence supposed to have taken place really occurred, since there must then have been numerous deep and quiet fjords specially fit to harbor vast colonies of marine creatures, as such places are known to do at the present day. In southern England the residuary soil upon the surface both of the granite bosses of Cornwall and Devon and over large areas of the chalk country demonstrate the long-continued freedom of that area from subsidence. Nor are there any positive evidences of subsidence of more than 200 or 300 feet in Scotland, if even so much as that.

There would seem to remain, therefore, no way of accounting for the shell-bed at Ketley except on the theory of Professor Lewis that they were pushed along with other transported material by the Irish sea glacier. If one inquires further into the more specific processes by which the underlying sand was deposited and the overlying till spread over it, it is impossible to give more than a tentative explanation. The recent studies of the Alaskan glaciers by Professor Reid, Mr. Cushing and Mr. Russell show us how complicated are the deposits near the front of a great glacier. The ice itself becomes covered with débris and forms barriers and furnishes at once both the margins of small lakes and streams and the water and

silt to fill them; so that on a temporary advance it is easy enough to see how even in an open valley all sorts of deposits may take place in rapid succession.

The bearing of these discoveries concerning the elevated shell-beds in the glacial deposits of England is very significant with reference to the general theory of an interglacial period. In fact, the principal necessity for the supposition of an interglacial period in England disappears with this explanation. So far as the evidence goes, the glacial period in England seems to have been a grand unity, characterized only by minor episodes and by periods of the prevalence, first, of the ice moving from Scandinavia and the Welsh mountains and, secondly, of that which proceeded more slowly from the sources of the great Irish-sea glacier. There is now left no sufficient reason for interposing a vast interglacial subsidence between the prevalence of the ice coming from the first centers mentioned and that coming from the other two. The upper till and the lower, so far as found in England, is probably the product not of two distinct glacial periods, but of minor episodes in a single period.

The Society then took a recess and visited the Columbus Club in acceptance of the invitation extended the previous day by the colleagues of Dr. Edward Orton.

At 3 o'clock p. m. the Society reassembled.

The first paper of the afternoon, read by W J McGee in the absence of the author, was entitled—

THE CHAMPLAIN SUBMERGENCE.

BY WARREN UPHAM.

(*Abstract.*)

Marine fossils in beds overlying the glacial drift prove that the northeastern part of North America stood lower than now in the Champlain epoch—that is, the time of departure of the last ice-sheet. This depression, which seems to have been produced by the vast weight of the ice, was bounded on the south approximately by a line drawn from near the city of New York northeastward to Boston and onward through Nova Scotia. When the ice-sheet was being withdrawn from this region the country south of this line stood somewhat higher than now, as is shown by the channels of streams that flowed away from the melting ice and ran across the modified drift plains which form the southern shores of Long island, Martha's Vineyard, Nantucket and cape Cod. A subsequent depression of the land there, continuing perhaps uninterruptedly to the present time, has brought the sea into these old river courses; but north and northwest of this line the land at the time of recession of the ice-sheet was lower than now and the coast and estuaries were more submerged by the sea. Fossiliferous beds of modified drift, supplied from the melting ice-sheet and resting on the till, show that the vertical amount of the marine submergence when the ice-sheet disappeared was 10 to 25 feet in the vicinity

of Boston and northeastward to cape Ann; about 150 feet in the vicinity of Portsmouth, New Hampshire; from 150 to about 300 feet along the coast of Maine and southern New Brunswick; about 40 feet on the northwestern shore of Nova Scotia; thence increasing westward to 200 feet in the Bay of Chaleurs, 375 feet in the Saint Lawrence valley opposite the Saguenay, and 520 feet at Montreal; 300 to 400 feet, increasing from south to north, along the basin of lake Champlain; about 275 feet at Ogdensburg, and 450 feet near the city of Ottawa; 300 to 500 feet on the country southwest of James bay; in Labrador little at the south, but increasing northward to 1,500 feet at Nachvak, according to Dr. Robert Bell, and in northern Greenland and Grinnell land from 1,000 to 2,000 feet.

That the land northward from Boston was so much lower while the ice-sheet was being melted away is proved by the occurrence of fossil mollusks of far northern range, including *Leda arctica*, Gray, which is now found living only in arctic seas where they receive muddy streams from existing glaciers and from the Greenland ice-sheet. This species is plentiful in the stratified clays resting on the till in the Saint Lawrence valley and in New Brunswick and Maine, extending southward to Portsmouth, New Hampshire. But it is known that the land was elevated from this depression to about its present height before the sea here became warm and the southern mollusks, which exist as colonies in the Gulf of Saint Lawrence, migrated thither, for these southern species are not included in the extensive lists of the fossil fauna found in the beds overlying the till.

In the Saint Lawrence basin these marine deposits reach to the southern end of lake Champlain, to Ogdensburg and Brockville, and at least to Pembroke and Allumette island, in the Ottawa river, about 75 miles above the city of Ottawa. The isthmus of Chignecto, connecting Nova Scotia with New Brunswick, was submerged, and the sea extended 50 to 100 miles up the valleys of the chief rivers of Maine and New Brunswick.

From the Champlain submergence attending the departure of the ice the land was raised somewhat higher than now; and its latest movement from New Jersey to southern Greenland has been a moderate depression. The vertical amount of this post-glacial elevation above the present height and of the recent subsidence on all the coast of New Jersey, New England and the eastern provinces of Canada is known to have ranged from 10 feet to a maximum of at least 80 feet at the head of the bay of Fundy, as is attested in many places by stumps of forests, rooted where they grew, and by peat beds now submerged by the sea.

At the time of final melting of the ice-sheet this region, which before the ice age had stood much higher than now, was depressed, and the maximum amount of its subsidence, as shown by marine fossils at Montreal and northwestward to Hudson bay, was 500 to 600 feet. Subsequently our Atlantic coast has been re-elevated to a height probably 100 feet greater than now; and during the recent epoch its latest oscillation has been again downward, as when it was ice-covered. The rate of depression since the discovery of America has probably been 1 to 2 feet, or less, in a hundred years. In the basin of Hudson bay, however, the observations of Dr. Bell show that the re-elevation from the Champlain submergence is still in progress, its rate, according to his estimate, reaching probably 5 to 7 feet during each century.

Turning to the glaciated regions of Europe, we find similarly that the countries which were ice-covered, after having been much higher before the ice accumulation, as shown by fjords, were depressed somewhat below their present height when the ice disappeared. The supposed great submergence, however, up to 1,200

and 1,500 feet or more, which has been claimed by British geologists for northern Wales, northwestern England and a part of Ireland, on the evidence of marine shells and fragments of shells in glacially transported deposits, is shown by Belt, Goodchild, Lewis and others to be untenable. Indeed, these fossils, not lying in the place where they were living, give no proof of any depression of the land, since they have been brought by currents of the ice-sheet moving across the bed of the Irish sea. But it is clearly known by other evidence, as raised beaches and fossiliferous marine sediments, that large portions of Great Britain and Ireland were slightly depressed under their burden of ice and have been since uplifted to a vertical extent ranging probably up to a maximum of about 300 feet.

In Scandinavia the valuable observations and studies of Baron de Geer have supplied lines of equal depression of the land at the time of the melting away of the ice. This region of greatest thickness of the European ice-sheet is found to have been depressed to an increasing extent from the outer portions toward the interior. The lowest limit of the submergence, at the southern extremity of Sweden, is no more than 70 feet above the present sea-level, and in northeastern Denmark it diminishes to zero; but northward it increases to an observed amount of about 800 feet on the western shore of the Gulf of Bothnia, near latitude 63°. Along the coast of Norway it ranges from 200 feet to nearly 600 feet, excepting far northward, near North cape, where it decreases to about 100 feet. In proportion with this observed range of the subsidence on the coast of Scandinavia, its amount in the center of the country was probably 1,000 feet.

A very interesting history of the post-glacial oscillations of southern Sweden has been also ascertained by Baron de Geer, which seems to be closely like the post-glacial movements of the northeastern border of North America. As on our Atlantic coast, the uplift from the Champlain submergence in that part of Sweden raised the country higher than now. The extent of this uplift appears to have been about 100 feet on the area between Denmark and Sweden, closing the entrance to the Baltic sea, which became for some time a great fresh-water lake. After this another depression of that region ensued, opening a deeper passage into the Baltic than now, giving to this body of brackish water a considerably higher degree of saltness than at present, with the admission of several marine mollusks, notably *Littorina litorea*, L., which are found fossil in the beds formed during this second and smaller submergence, but are not living in the Baltic to-day. Thus far the movements of southern Sweden are paralleled by the post-glacial oscillations of New England and eastern Canada; but a second uplifting of this part of Sweden is now taking place, whereas no corresponding movement has begun on our Atlantic border. It seems to be suggested, however, that it may yet ensue. The subsidence has ceased or become exceedingly slow in eastern New England, while it still continues at a measurable rate in New Jersey, Cape Breton island, and southern Greenland.

So extensive agreement on opposite sides of the Atlantic in the oscillations of the land while it was ice-covered, and since the departure of the ice-sheets, has probably resulted from similar causes, namely, the pressure of the ice-weight and the resilience of the earth's crust when it was unburdened. The restoration of isostatic equilibrium in each country is attended by minor oscillations, the conditions requisite for repose being over-passed by the early reëlevation of outer portions of each of these great glaciated areas.

In view of this harmony in the epeirogenic movements of the two continents during the Glacial, Champlain, and Recent periods, it seems evident that the close

of the Ice age was not long ago, geologically speaking, for equilibrium of the disturbed areas has not yet been restored. Furthermore, the close parallelism in the stages of progress toward repose indicates nearly the same time for the end of the Glacial period on both continents, and approximate synchronism in the pendulum-like series of post-glacial oscillations.

Remarks were made by B. K. Emerson.

The next paper was presented in abstract by J. S. Diller—

THE ELEOLITE-SYENITE OF LITCHFIELD, MAINE, AND HAWES' HORNBLENDE-SYENITE FROM RED HILL, NEW HAMPSHIRE.

BY W. S. BAYLEY.

The paper was discussed by J. E. Wolff, B. K. Emerson and J. S. Diller. It is printed as pages 231–252, with plate 7, of this volume.

The next paper was read by W J McGee, the author being absent:

NOTE ON THE MIDDLETON FORMATION OF TENNESSEE, MISSISSIPPI AND ALABAMA.

BY JAMES M. SAFFORD.

It is known that in September last a party of geologists organized and carried out an expedition having for its object the reëxamination and study of typical sections in Tennessee, Mississippi, Alabama and other southwestern states. The expedition, organized in Washington under able leadership, was a most successful one and will be long remembered for the pleasure it afforded all members of the party. Its history has been given elsewhere, and need not be repeated here.

The party stopped for a time at Oxford, the site of the university of Mississippi. While here the writer caught sight of some peculiar rock fragments containing Eocene shells, which he thought must have come from localities known to him in Tennessee. Dr. Hilgard, however, who was one of the party and near at hand, said they were from Mississippi, and pointed out the page in his "Agriculture and Geology of Mississippi" (1860) on which the rock from which they came is described. The rock is that indicated as "clay-sandstone," division number 2 of the section on page 112. Dr. Eugene A. Smith, also a member of the party, informed us that the same formation occurs in Alabama.

The Tennessee rock is strikingly like that of Mississippi and could not be told from it. It occurs in Tennessee, in Hardeman county, at a number of points. One of these is the town of Middleton, on the Memphis and Charleston railroad, and for many years I have spoken of it as the *Middleton bed*.

And so it was that three of us, representing as many states—Tennessee, Mississippi and Alabama—were, by a happy accident, thrown together and made to see that our several rocks were one and the same formation.

The particular and characteristic rock referred to above is rarely more than three feet thick, but it has associated with it a group of layers of much greater thickness. The group has importance in the fact that it is the lowest Eocene in the states

mentioned. With the concurrence of Dr. Hilgard and Dr. Smith, I propose for it the name of *Middleton formation.*

An article on the formation is in the hands of the editors of the American Geologist for publication. This will be followed by others.

Mr. McGee also read the next paper for the author, who was absent:

THE AGE AND ORIGIN OF THE LAFAYETTE FORMATION.

BY E. W. HILGARD.

The paper is printed in the American Journal of Science, 3d series, volume xliii, 1892, pages 389–402.

The following paper was read by title:

PALÆASTER EUCHARIS, HALL.

BY A. H. COLE.

The fossil which calls forth the following observations is an impression of the oral surface of a starfish found in July last in the Hamilton shales in the quarry belonging to Colgate university at Hamilton, New York.

The fossil has been compared with the type specimen from which Dr. Hall's species was described and figured. As it agrees with the type in general, though varying from the description in certain important characters, and by reason of its perfect preservation reveals hitherto unknown details of structure, it seems best to review the original description in so far as it relates to the oral surface.

"PALÆASTER EUCHARIS (n. s.).*

"Body rather large: the largest individual being one inch and seven-eighths from the center of the body to the extremities of the rays; the whole having a robust aspect; rays acutely pointed at the extremity.

"Ventral surface having deep ambulacral grooves, bordered by two ranges of strongly tuberculose plates; the outer marginal range consisting of twenty-seven or twenty-eight plates, besides a large, round, terminal or axillary plate; the others are wider than long in the basal portion of the ray, becoming gradually shorter toward the extremity, where they are rounded.

"All the marginal plates are visible from the upper side, and usually appear as an additional range of plates on each margin of the ray, making five with the three properly belonging to the upper surface.

"The inner range bordering the ambulacra (adambulacral plates) are smaller than the marginal plates, about thirty-eight to forty in number; the basal or oral plates are triangular, those of the adjacent rays uniting by their longer margins, and with a single minute plate situated at these points.

"The plates of the exterior surface, both upper and lower, present a granulose or striato-granulose surface, which appears to have been produced by short setæ or spines, and at the angles of the rays the marginal plates are armed by a few spines, which are as long or longer than the transverse diameter of the plates.

"Ambulacra composed of a double range of short broad poral plates (ossicula), equal in number to the adambulacral plates; their outer ends excavated on the posterior border, forming a comparatively large pore, just within its junction with the adambulacral plate. There appears to have been but one range of pores in each set of ossicula, but these are large, distinct, and pass between the plates.

20th Ann. Rep. N. Y. State Cabinet of Nat. Hist., 1867, p. 287, pl. ix, figs. 3, 3, 3*a* and 4.

"In the collection there is an impression of a single ambulacral area of this species, which is spread open laterally, and measures about two and a half inches in length by nearly three-fourths of an inch in width in the middle, broadly petaloid in shape, and showing the form and number of the poral plates, with the position of the pores and their junction with the adambulacral plates."

The specimen in hand differs from this description in the following particulars:

The terminal or axillary plate of the marginal range is elliptical in form, with its major axis directed toward the adjacent reëntrant angle. Its surface is granulose and bears three short, thick, blunt pointed spines. The marginal plates bordering each reëntrant angle bear similar but more slender spines, which are not "as long as the transverse diameter of the plates." The spines are arranged in a row near the distal margin of the plates and number five on the plates at the angle, the number and size decreasing until they disappear at the sixth or seventh plate from the angle. All the marginal plates are nearly smooth on the free margin and become gradually more granulose toward the line of junction with the adambulacral plates. The margins of the rays show in three places that the ventral marginal plates were visible from above, agreeing with the original description.

The adambulacral plates are apparently less numerous than stated in the original description, and "the single minute plate" at the points of the pairs of the oral plates is visible in this specimen and is armed with two relatively long, slender spines which are apparently but a part of the full armature. The adambulacral plates, including the triangular oral plates, bear well defined spines, which are shorter than the diameter of the plates to which they are attached. Each plate bears two spines so near to the distal margin that the impressions of the short and obtusely pointed spines frequently bridge the well defined groove between the adjacent adambulacral plates and terminate near the proximal margin of the next plate. The spines decrease in size toward the end of the ray and a few plates show only one spine. The plates of this range are thick, equaling two-thirds to three-fourths the depth of the groove. The vertical angles of the faces forming the lateral walls of the groove are beveled, so that lateral extensions of the groove are formed between each two plates on the same side. These lateral expansions are narrow and shallow at the oral surface, deeper and wider inward; so that the faces of the adambulacral plates near their junction with the poral plates are reduced to a narrow edge which projects inward and nearly touches the corresponding plate on the other side of the groove. The general appearance of the fossil as well as the outline of the rays at the points where the broken block presents a transverse section of them indicates that the plates have their normal position, not having suffered distortion by pressure.

The ambulacral plates are shown by a well defined mold of their under or external surfaces. The soft matrix which filled the ambulacral furrow pressed upon the membranes connecting the ambulacral plates and occupying their pores, and as these membranes decayed it was forced by gentle pressure into the pores and between the edges of the plates. The mold of the groove is less than one-eighth of an inch in width in a ray measuring five-eighths at its base. The upper surface of the mold bears a narrow longitudinal median ridge which marks the junction of the two ranges of ambulacral plates. Similar transverse ridges, which are continuous with the lines marking the junction of the inner faces of the adambulacral plates, mark the proximal and distal margins of the ambulacral plates. These ridges do not cross at a right angle to the median line, but include between their proximal sides an angle of about 125°. These ridges indicate that the ambulacral and adambulacral plates were equal in number, and that the former

were united in pairs along a straight median line rather than in an alternate right and left arrangement along a zigzag line, as is shown in Dr. Hall's figures. The pores described as being "excavated in the posterior border of the ambulacral plates and just within their junction with the adambulacral plates" are not clearly shown on this specimen, although there are irregular and inconstant markings at some of the points of the molds of the lateral extensions of the groove. A series of pores near the median line is indicated by a series of small rounded prominences on each side of the median ridge and very close to it. These prominences are opposite the lateral expansions of the groove, and one is found on the mold of each ambulacral plate. The pores appear to have been perforations very near the edges of the plates, or excavations in their margins.

Another specimen of the same species from the same quarry, which has recently been loaned to me for examination, shows the spines on the axillary and adambulacral plates, but the imperfect preservation of the fossil renders them less distinct. The mechanically reproduced photograph (plate 15) accompanying this paper shows that one ray has an obtusely rounded extremity which was, at first, considered as possibly a normal character, as it is in *Palæaster granulosa*. The finding of spines on the oral surface also seemed to ally the specimen with *P. granulosa*; but the presence of spines, as in the specimen described, together with acutely pointed rays, both of which characters are seen in the second specimen from the same quarry, are conclusive evidence that the specimen is *P. eucharis*.

These fossils are extremely rare in the Hamilton shales. I have been able to learn of the finding of only four in this vicinity, or, including the one mentioned by Dr. Hall, the number known is five. Other localities have contributed a small number.

In the absence of the author the following paper was presented in abstract by J. E. Wolff:

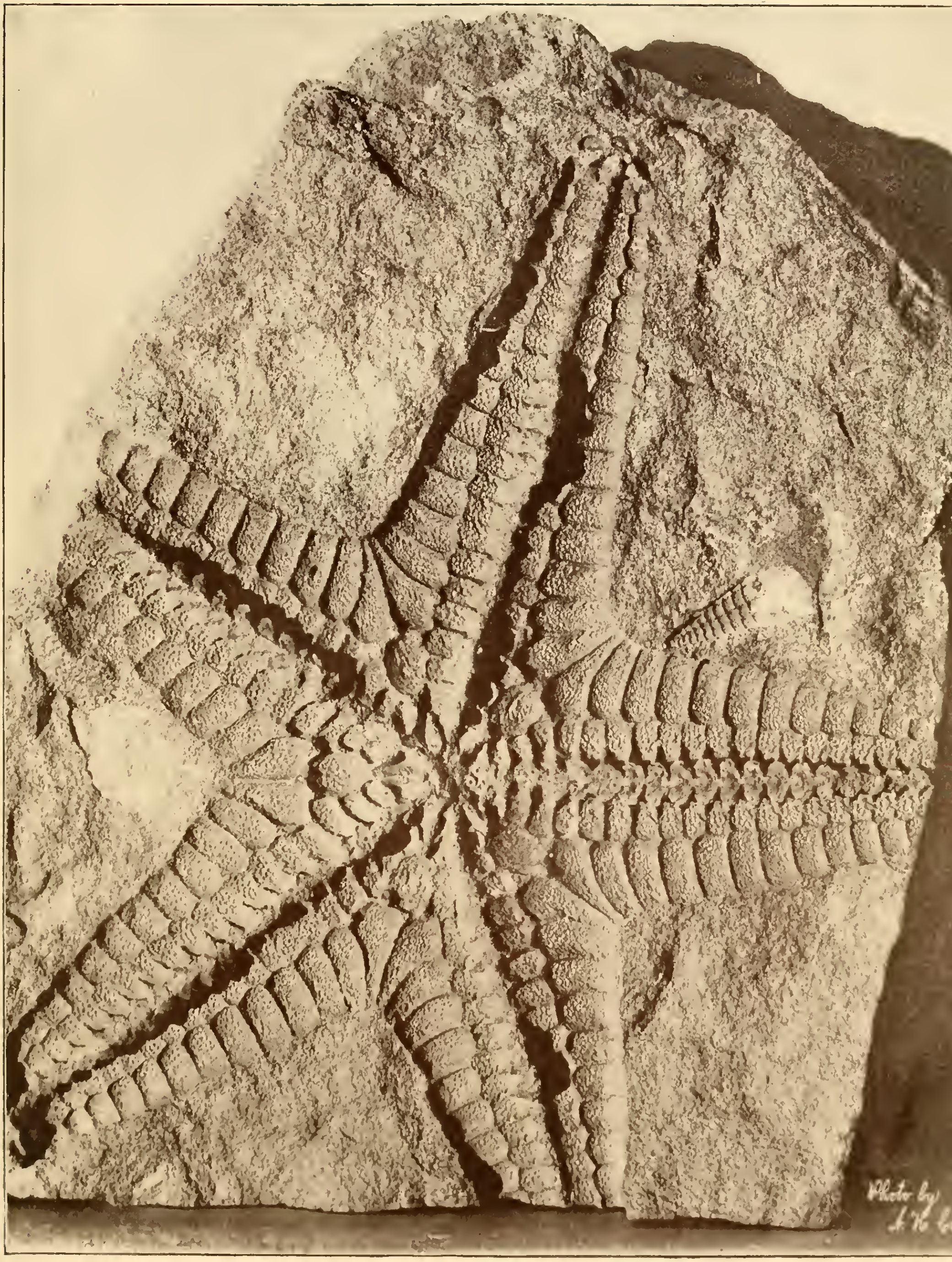
ON THE STRUCTURE AND AGE OF THE STOCKBRIDGE LIMESTONE IN THE VERMONT VALLEY.

BY T. NELSON DALE.

Contents.

Introduction.

Between the Green mountain range and the Taconic range and on the western side of the Vermont valley lies a ridge which, beginning with Pine hill in Rutland, extends southward through the towns of Clarendon and Wallingford about 24 miles



PALÆASTER EUCHARIS, HALL ·2½ DIAM

to Danby hill in Danby.* Its altitude above Otter creek ranges from about 400 to 1,100 feet.

This ridge was described by the geologists of the Vermont survey † as an anticlinal of quartzite flanked both on the east and west in places by Talcoid schists, in others by the Eolian limestone, and the schists forming its southern end were represented as cut off from those of the Dorset mountain mass by an east-west fault.

Professor C. H. Hitchcock in his sections ‡ omits the anticlinal structure from the quartzite, calls the schists on the eastern side Cambrian slates, and the limestone on both sides Cambro-Silurian.

Mr. J. E. Wolff, in his paper read before this Society last December, shows the composition of the northern end of the ridge to be as follows, beginning at the eastern side: (1) Cambrian limestone overlying (2) Cambrian quartzite and its associated conglomerates and gneisses; then (3) schist overlying (4) the lower Silurian limestone of the Center Rutland valley. He also shows the continuity at the surface of the quartzite of the ridge with that of the western flank of the Green mountain range. He would explain the abnormal relations between the quartzite of the ridge and the Stockbridge limestone on the west by "A great thrust plane by which the Cambrian is made to overlie the lower Silurian limestone." §

During the past summer, after examining Mr. Wolff's localities and finding, as he says, that they do not yield a decisive proof of such a thrust plane,‖ I crossed the ridge at several points between Rutland and Danby to find a more favorable locality. Such an one was found in Clarendon, where a deep and wide saddle in the ridge afforded many excellent outcrops.

A contour map on a scale large enough to show the details in the wooded areas was here of prime importance. Such a map was therefore made, and a reduced copy of it is here given (plate 16). In addition to the usual symbols for the strike and dip and pitch of the stratification-foliation, those used by Dr. H. Reusch, of Christiania,¶ to indicate the strike and dip of the cleavage-foliation have been employed.

Areal Geology.

The areal geology is simple. The eastern half of the ridge consists of the quartzite, conglomerates and schists of the Cambrian (including, perhaps, some older gneisses and eruptives), coming in contact in the valley on the east at one or two points with the Stockbridge limestone. This quartzite is in contact on the west, along the axis of the ridge, with limestone in the lower part of the saddle, and with a schist overlying that limestone in the higher parts both north and south. In the southern half of the map the limestone area is only 650 feet wide, and the schist tapers to about 250 feet. Both schist and limestone are here followed westwardly by another mass of quartzite, which dips normally under the limestone of the Tinmouth valley, which is continuous with that of center Rutland.

* Danby hill lies two miles north of the northern part of Dorset mountain, which in the Vermont report is called Danby mountain.

† Report on the Geology of Vermont by E. and E. and C. H. Hitchcock and A. D. Hager, 1861: vol. I, p. 350, 353; vol. ii, p. 763, pl. viii, fig. 2; pl. xvi, sec. iv, v.

‡ Geol. sections across N. H. and Vt.: Bull. Am. Mus. Nat. Hist., vol. 1, no. 5, 1881, pl. 16, sec. iv, v, vi.

§ "On the Lower Cambrian Age of the Stockbridge Limestone." Bull. Geol. Soc. Am., vol. 2, 1890, pp. 331–338.

‖ Op. cit., p. 337.

¶ Neues Jahrb. für Min., Geol., etc, V Beilageband, Stuttgart, 1887.

STRUCTURE AND AGE.

Sections.—The five sections herewith (figure 5) show the structural relations. In section *A*, which crosses the lowest part of the saddle, the Cambrian quartzite forms on the eastern side an anticlinal and a synclinal, the latter infolding some 65 feet of the lower part of the Stockbridge limestone. West of this, owing to a fault, a block of this limestone about 650 feet wide has slidden down between two masses of quartzite. Beyond the quartzite dips normally under the limestone, and this includes a bed 25 feet thick and about a quarter of a mile long filled with fossils, determined by Mr. C. D. Walcott as *Hyolithes americanus*, Billings,* with the following species doubtful: *H. imper*, *H. communis* and *H. similis* (very doubtful); the whole indicating, as he writes,† "The upper horizon of the lower Cambrian or Olenellus zone." As there are about 470 feet of limestone between this bed and the underlying quartzite, that much of the limestone must be regarded as Cambrian.

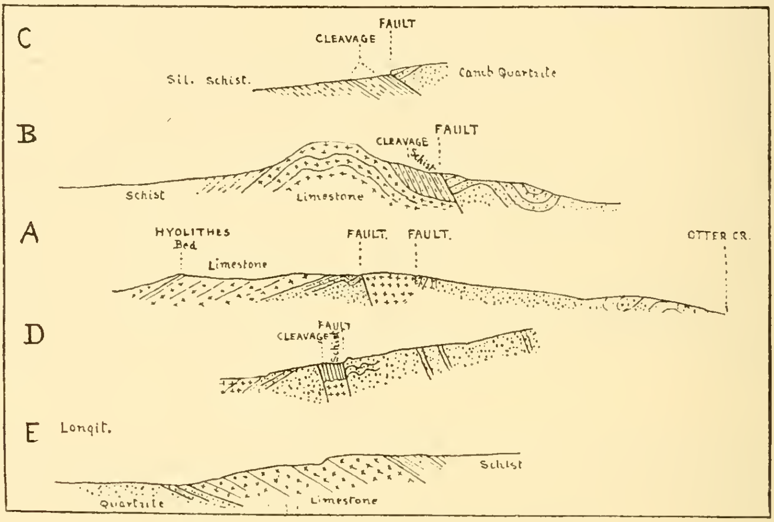


FIGURE 5.—*Sections through Rutland-Danby Ridge.*

brian. These pteropods appear more frequently in transverse sections, but also in every sort of section. Each individual or fragment generally forms the center of a concretion-like body from ¼ to 1 inch in diameter (figure 6). These bodies, however, require further study. The rock is bluish-gray. The oolitic structure appears best on weathered surfaces.

In section *B*, about a quarter of a mile north of *A*, the eastern fault-plane alone appears, the western having died out or merged into it. Here the quartzite shows a synclinal and an anticlinal, and is brought by the fault to the level of the schists overlying the limestone.

* E. Billings—"On some New Species of Paleozoic Fossils: Canadian Naturalist, Dec., 1871, reprinted in Am. Journ. Sci., 3d ser., vol. iii, 1872, p. 352; C. D. Walcott—"Studies on the Cambrian Fauna of North America": Bull. 30 U. S. Geol. Surv., 1886, p. 132, pl. xiii; also "The Fauna of the Lower Cambrian or Olenellus Zone": 10th Ann. Rep. U. S. Geol. Surv., 1890, p. 620, pl. lxxv.

† November 13, 1891.

In section *C*, about three-quarters of a mile farther northward, the quartzite overlies the schist.*

In section *D*, south of *A* and about half a mile south of the deepest part of the saddle, a block of the schist which belongs over the limestone is wedged in between quartzite masses. The structure is like that in section *A*, but occurs higher up the hill where the schists have escaped erosion.

Section *E* is longitudinal, from the deepest part of the saddle northward. Owing to the northerly pitch of the anticlinal at this point, together with the deep erosion of the ridge, the entire thickness of the limestone from the quartzite to the schist is here exposed along a north-south line, and the three rocks are seen in their normal relations with well observed contacts. This section thus yields a measure-

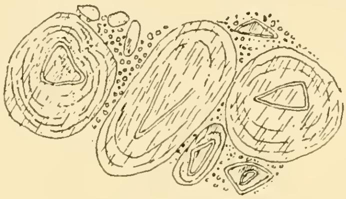


FIGURE 6.—*Structure of Hyolithes Limestone.*

ment of the limestone, which amounts to from 1,000 to 1,400 feet, according as the average pitch is taken as 25° or 35°; 1,200 feet is probably correct.

The upper Part of the Limestone and the Schist.—The northeastern corner of the map (plate 16) overlaps the extreme southern end of Mr. Wolff's map and includes the fossil locality given by him southeast of Clarendon Springs, where Mr. Aug. F. Foerste found in a sandy limestone "crinoid stems and plates and a small branching bryozoan with large cells."† This locality (339 on map) is in a small lenticular area of limestone surrounded by schist, the former of which may be regarded either as representing the schist by different sedimentation, and thus of the same age as the schist, or as a minor anticlinal in the uppermost part of the Stockbridge limestone. During the past summer Mr. Foerste found fragments of crinoid columns and a *Heliolites?* (Walcott's determination) in a similar but smaller limestone area (260 on map) within a few feet of the fault. This from its position can hardly belong to the limestone, but must represent the age of the schist. Mr. Foerste also found on the eastern side of the ridge, near South Wallingford, in the limestone near the schist, besides the usual crinoid stems, the following: *Streptelasma*, sp.?; a coral much like *Heliolites*; and cross-sections of strophomenoid shells—all determined by Mr. Walcott, who refers the fossils generally to the Chazy-Trenton-Lorraine faunas.

From all these facts it follows that the upper part of the limestone and certainly a portion of the overlying schist are of Lower Silurian age.

The Fault.—As will be seen by examining the sections, the amount of displacement along the fault plane equals the entire thickness of the limestone, besides about 300 feet of the overlying schists, *i. e.*, 1,500 feet. The line of the fault is marked in places by large quartz veins and on Pine hill by eruptives. The fault can be followed to a point west of South Wallingford. On the southern side of

*The structure here may even be more extreme than shown in the section.

†Op. cit., p. 336.

Mill brook, at the northern foot of the Dorset mountain mass, the quartzite and blue quartz conglomerate reappear, although not shown on the Vermont report, with the lower Silurian schists in contact on the west. This fault thus trends at right angles to the east-west fault described in that report.

The obscurity of the fault on the ridge at many points is due to its bringing together certain dark mica (sericite) schists, consisting of alternating more quartzose with more micaceous laminæ, which belong to the Cambrian quartzite series, on the east, with the dark but not banded and generally more or less graphitic sericite schists of the lower Silurian on the west. The fault is also further obscured by a cleavage-foliation in both schists, dipping at a high angle eastward and parallel to the fault plane, whereas the stratification of both Cambrian and Silurian schists, except in rare instances, dips westward in low undulations, as can be made out here and there and as the vertical and horizontal relations of the limestone and the Silurian schist at Clarendon necessitate in the case of the latter.

RÉSUMÉ.

The Rutland-Danby ridge is a complex anticlinal of gneiss and Cambrian quartzite, conglomerate and schist flanked by Cambrian limestone and lower Silurian limestone and schist. The upper part of the Cambrian quartzite on its western side dips under the base of the limestone of the Tinmouth, Center Rutland valley, and on its eastern side, as shown by Mr. Wolff at Pine hill, under the base of the limestone of the Vermont valley.

Mr. Wolff has shown the Cambrian age of the base of the limestone on the eastern side, and this paper shows the corresponding fact on the western side. Admitting that the schist overlies the Stockbridge limestone in these valleys at about the same horizon, the entire thickness of that limestone in this part of Vermont may be reckoned at 1,200 feet, and the *Hyolithes* bed at West Clarendon shows that about 470 feet of the lower part of this belong to the Cambrian; but the upper part of the Stockbridge limestone has been shown by Reverend Augustus Wing's fossil localities at West Rutland * and Mr. Foerste's collections at Center Rutland, Clarendon Springs and South Wallingford to be of Lower Silurian age, and to this age belongs also a part, if not all, of the overlying mass of schist.

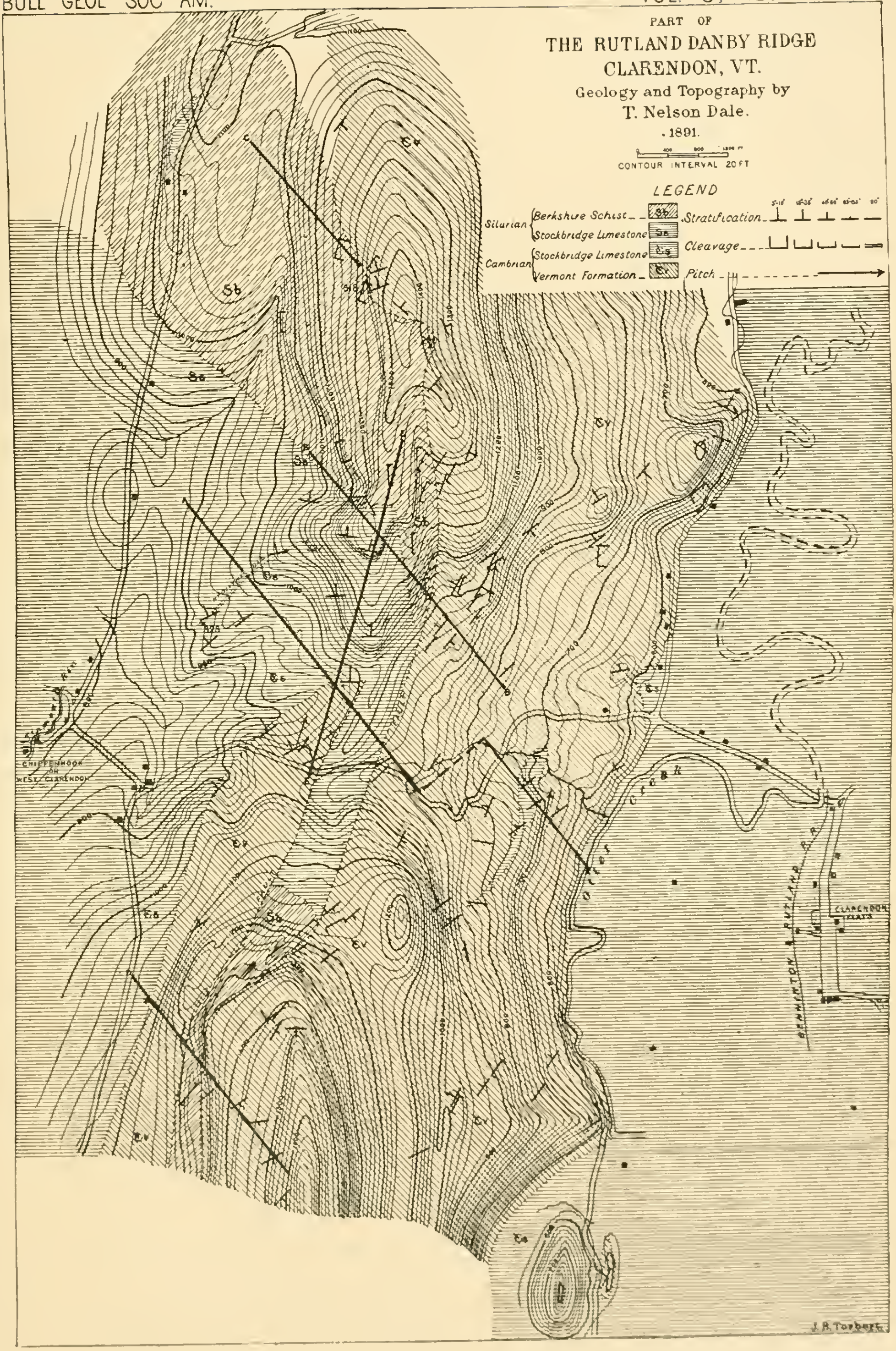
Owing to a fault extending from Pine hill in Rutland to Wallingford, about 16 miles, causing a displacement measured at Clarendon as 1,500 feet, the Cambrian quartzite and conglomerate and schist have been brought up to the level of the Lower Silurian schists, which latter they in one place overlie. It is owing to the anticlinal structure, complicated by faults, of the Rutland-Danby ridge that at some points the base of the Stockbridge limestone with its Cambrian fauna, while at others, not far off, the top with its Lower Silurian fauna, is alone exposed.

Besides these general results, many minor facts were established and the explorations were continued southward on the Dorset mountain mass, but they are not yet sufficiently elaborated for publication.

Professor B. K. Emerson spoke as follows:

It is a pleasure to express my high appreciation of the importance of the results reached in this investigation and of the care and fullness with which it was con-

* "An Account of the Discoveries in Vermont Geology of the Reverend Augustus Wing," by J. D. Dana: Am. Journ. Sci., 3d ser., vol. xiii, 1877, p. 332.


PART OF
THE RUTLAND DANBY RIDGE
CLARENDON, VT.
Geology and Topography by
T. Nelson Dale.
1891.
CONTOUR INTERVAL 20 FT
LEGEND
Silurian
Berkshire Schist
Stockbridge Limestone
Cambrian
Stockbridge Limestone
Vermont Formation
Stratification
Cleavage
Pitch
CHIPPENHOOK OR WEST CLARENDON
Otter Creek
CLARENDON FLATS
BENNINGTON & RUTLAND R.R.
J. R. Torbert

ducted. The bearing of Mr. Dale's excellent work is closely related to the results detailed in the paper just read by Mr. Hobbs. Similar phenomena to those described by both gentlemen occur in the Cambrian gneisses at the large quarries at Monson, Massachusetts, where it has been my fortune recently to discover traces of a conglomeratic structure. The distortion of the pebbles consists here in a flattening at right angles to the pressure (east to west) and a great elongation in the vertical direction, with a lesser change in the third direction (north to south). The tension in this latter direction expresses itself in an expansion of the blocks from north to south when quarried, and which is so strong as to cause great blocks to crack off from the face of the quarry under favorable circumstances with loud detonations. This tension is evidently connected with mountain-making compression. These interesting phenomena are fully described in the publications of Professor Niles, chiefly in the Proceedings of the Boston Society of Natural History.

The last paper was read by title:

A CONTRIBUTION TO THE GEOLOGY OF THE GREAT PLAINS.

BY ROBERT HAY.

It is a fact that the study of the geology of the Plains has in times past been slighted by geologists. As soon as it was possible to travel quickly to the Rocky mountains, thither the naturalists of all sorts went. The upturn of the strata on their flanks made it possible to study rocks of almost the whole geologic scale in areas of only a few miles in extent. The neighboring Archean rocks, the faults and metamorphoses, were too fascinating to leave for the slower investigations of the valleys of the region of the Plains. Still all who crossed the Plains made some observations, and little by little knowledge was acquired that made some generalizations possible. We wish here to add some facts which, with previous knowledge, will possibly justify a few other generalizations.

From the southern slope of the Black hills, in Dakota, to the Panhandle of Texas, and from the 100th to the 104th meridian, the surface terrane of the Plains on the level interfluvial spaces is a fawn-colored calcareous and arenaceous clay, which is of late Tertiary age in its oldest parts and probably shades into post-Pleistocene on its eastern boundaries. It includes the *Equus* beds of Cope, but usually is barren of fossils. It varies from 3 or 4 feet to 200 feet thick. It is thinned off by Quaternary erosion on the slopes of the valleys. This erosion has also leached out in many places all its calcareous and argillaceous ingredients, and left its sand to be piled into eolian dunes. The bottom of this Plains marl rests on a much eroded surface which is mostly formed of another Tertiary formation, but in places the immediately subjacent rock is some Cretaceous terrane.

This Tertiary formation under the marl is, in the northern part, the White River beds, which in Pine ridge attain a thickness of 700 or 800 feet. South of the 40th parallel and east of the 103d meridian this gives place to the Loup Fork, which rests on the Cretaceous without the intervention of the White River beds, and which is characteristically developed toward the northeast in Nebraska. In this region, from about the 41st parallel to the 35th, the Loup Fork has a varying thickness of from a very few feet or a mere trace to nearly 100 feet. These thicknesses are those found in outcrops in the valleys of modern erosion. We cannot be certain of it elsewhere; we can only infer approximately. It is the main water-bearing

stratum of this region of the Plains, so that wells piercing it never go through it. As with the marl, erosion has left sand behind, which aids the formation of dunes. I have called these terranes the *Tertiary grit*.

The bottom of the Neocene formation—White River or Loup Fork—rests on a much eroded surface of Mesozoic strata. This pre-Neocene erosion is shown, as well as the later one, in all the deeper valleys of the Plains, and it is manifest that the two succeeding erosions have largely cut down the valleys on the old pre-Neocene lines.

This being true, it is also true that some of the pre-Neocene and mid-Neocene valleys have not been reopened by modern erosion. They are to be traced by lines of basin-like depressions, and in Nebraska there are examples of modern erosion having cut them transversely.

When beneath the Tertiaries we examine the subjacent Mesozoic formations, we find a thickening of them toward the north and northwest. This is what we note in the Tertiaries. Whether this is due to original deposition or to the pre-Neocene erosion, or to both, cannot be stated certainly; but it is a fact that from Platte river southward on the 102d or 100th meridian the outcrops of the Mesozoic strata in the river valleys are in descending order. Thus, on the 100th meridian we have in—

Republican	valley—Montana shales.				
Sappa	"	Colorado group—Niobrara.			
Prairie Dog	"	"	"	"	
Solomon	"	"	"	"	(lower part).
Smoky	"	"	"	"	
Walnut	"	"	"	Benton.	
Saw Log	"	"	"	Benton resting on Dakota.	
Arkansas	"	not shown.			
Crooked creek	"	Trinity.			
Cimarron	"	Red beds.			

The valley of the Canadian and Red rivers in the Panhandle of Texas, with a total section of 1,000 feet, shows nothing higher than the Trinity (at least in this longitude). This Cretaceous deposit is, as farther northward, overlain by the Tertiaries.

On the 102d meridian erosion has not proceeded so far and the outcrops are fewer. A little east of it we have in—

Republican	valley—Montana shales.		
Smoky	"	no outcrop.	
Whitewoman	"	Colorado—Niobrara (very slight outcrop).	
Arkansas	"	"	Benton.
Bear creek	"	Dakota.	
Cimarron	"	Trinity.	

This relation is represented graphically in figure 7. Reduced to scale for the known elevation, this diagram would show undulations of the strata that can only at present be taken as approximate to the reality till we have a more complete surface survey. It is not meant to affirm that the Dakota rests on the Trinity, but on the 102d meridian it is the next southerly outcrop. Further eastward it is known that shell-beds with *Gryphæa*, *Turretella*, etc. lie above the Trinity sands.

In the region of the Black hills the Cretaceous rocks are brought to view again in descending order northward. North of the hills they disappear in reverse order, and northeastward they thicken considerably, the Laramie of the lower Yellowstone and the Little Missouri "bad lands" attaining great thickness.

Two facts in the topography of the mid-Plains region are to be noted: (1) there is a decided valley between the Plains and the mountains, the former having a steep western escarpment from near Pueblo to near Cheyenne, Wyoming. This valley has its Tertiary formations, which are not here treated of. We would emphasize the fact that in the region above described the Plains formations are cut off from contact with the mountains. Running westward from Cheyenne is a ridge which constitutes the highest part of the Plains, running up to nearly 7,000 feet, and on this ridge the Plains formations abut against the mountains, overlapping the tilted Mesozoic and Paleozoic formations and resting on the granite. There are traces—the merest fragmentary patches—of this overlap down all the line of the foothills to Canyon City, but this ridge in south Wyoming is apparently the only place where modern erosion has not cut it away. It is the water-shed between the North Platte and South Platte drainage, and north of this, down the Chugwater to the North Platte, the western escarpment of the Plains is 1,000 feet high. (2) The other fact is that the streams between the Platte and the Arkansas and some both south and north of those rivers have their sources and courses on the Plains. Their

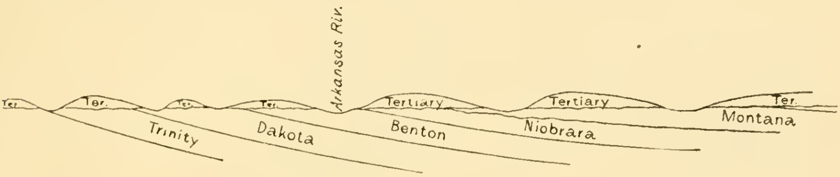


FIGURE 7.—*General Section on the 102d Meridian.*

valleys, from 200 to 500 feet below the level of the interfluvial plains, have been cut by the meteoric agencies of the region, unaided by the mountain snows, and they owe their perrenial supply of water to the springs that issue from the Tertiary grit. We are not treating here of the mauvaises terres of the Dakotas, but these Tertiary terranes in their weathering have, in the valleys of Nebraska and Kansas, been carved into fantastic forms of castles and buttes and palisades which vary by a local picturesqueness the intense monotony of the plains.

We desire here to call attention to the lines of investigation that will aid in the elucidation of the phenomena of the plains. We have mentioned that erosion has not proceeded so far (in the mid-Plains region) on the 102d as on the 100th meridian; but near the former line there are outcrops in many of the valleys which show the formations subjacent to the Tertiaries. Surveys on the 101st meridian would, in the Panhandle of Texas, cross the gashes cut by the Canadian and Red rivers to the depth of 1,000 feet; across Nebraska the same line would show very little outcrop of Cretaceous rocks. A survey on the 100th meridian from Dakota to the Rio Grande would reveal largely the structure of the plains, and shorter lines north-and-south further westward would show the variations of structure that characterize particular regions and the varying amount of the forces that have combined in the modern era to give the present physical characteristics to the region of the Great Plains.

Pending the close of the meeting, the following resolutions, presented by B. K. Emerson, were unanimously adopted :

"*Resolved*, That the thanks of the Geological Society of America be tendered—

"To the authorities of the State of Ohio for the use of the Hall of the House of Representatives during the fourth annual meeting of this Society ;

"To the Honorable George J. Karb, Mayor of the city of Columbus, for his cordial welcome to the Society and his generous tender of the hospitality of the city ;

"To the officers of the Ohio State University for their hearty welcome to this Society and their personal efforts to make the meeting a success ;

"To the Local Reception Committee, consisting of D. S. Kellicott, W. R. Lazenby, N. W. Lord, F. W. Sperr and H. A. Surface, for their personal interest in the meeting and their labor and solicitude, which contributed greatly to its pleasure and success."

With a few remarks, congratulating the Society on the completion of another year of prosperity and mutual good will, Mr. Gilbert declared the fourth annual meeting adjourned.

Register of the Columbus Meeting, 1891.

The following Fellows were in attendance at the meeting :

E. W. Claypole.
J. S. Diller.
E. T. Dumble.
B. K. Emerson.
H. L. Fairchild.
G. K. Gilbert.
C. W. Hall.
C. Willard Hayes.
Alpheus Hyatt.
Daniel W. Langdon, Jr.
W J McGee.
Thomas F. Moses.
Peter Neff.
William H. Pettee.
I. C. Russell.
Will H. Sherzer.
John C. Smock.
J. W. Spencer.
E. O. Ulrich.
I. C. White.
Arthur Winslow.
J. E. Wolff.
G. Frederick Wright.

Total attendance, 23.

Hjalmar Lundbohm, of the Geological Survey of Sweden, also attended the meeting.

LIST OF

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA.

OFFICERS FOR 1892.

President.

G. K. Gilbert, Washington, D. C.

Vice-Presidents.

Sir J. William Dawson, Monteal, Canada.
T. C. Chamberlin, Madison, Wis.

Secretary.

H. L. Fairchild, Rochester, New York.

Treasurer.

I. C. White, Morgantown, W. Va.

Councillors.

Class of 1894.

Henry S. Williams, Ithaca, New York.
N. H. Winchell, Ann Arbor, Mich.

Class of 1893.

George M. Dawson, Ottawa, Canada.
John C. Branner, Little Rock, Arkansas.

Class of 1892.

E. W. Claypole, Akron, Ohio.
Chas. H. Hitchcock, Hanover, N. H.

Editor.

W J McGee, Washington, D. C.

FELLOWS, JULY 1, 1891.

* Indicates Original Fellow (see article III of Constitution).
† Indicates decedent.

FRANK DAWSON ADAMS, Montreal, Canada; Lecturer on Geology at McGill College. December, 1889.

VICTOR C. ALDERSON, 6721 Honore St., Englewood, Ills. December, 1889.

TRUMAN H. ALDRICH, M. E., 92 Southern Ave., Cincinnati, Ohio. May, 1889.

HENRY M. AMI, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

*† CHARLES A. ASHBURNER, M. S., C. E. (Died December 24, 1889.)

GEORGE H. BARTON, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

WILLIAM S. BAYLEY, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

* GEORGE F. BECKER, Ph. D., Washington, D. C.; U. S. Geological Survey.

CHARLES E. BEECHER, Ph. D., Yale University, New Haven, Conn. May, 1889.

ROBERT BELL, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

ALBERT S. BICKMORE, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., N. Y. City; Curator of Anthropology in the American Museum of Natural History. December, 1889.

WILLIAM P. BLAKE, New Haven, Conn. August, 1891.

STEPHEN BOWERS, A. M., Ph. D., Mineralogical and Geological Survey of California, Ventura, California. May, 1889.

AMOS BOWMAN, Anacortes, Skagit Co., Wash. State. May, 1889.

EZRA BRAINERD, LL. D., Middlebury, Vermont; President of Middlebury College. December, 1889.

* JOHN C. BRANNER, Ph. D., Menlo Park, Cal.; Professor of Geology in Leland Stanford Jr. University; State Geologist of Arkansas.

* GARLAND C. BROADHEAD, Columbia, Mo.; Professor of Geology in the University of Missouri.

* WALTER A. BROWNELL, Ph. D., 905 University Ave., Syracuse, N. Y.

* SAMUEL CALVIN, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa.

HENRY DONALD CAMPBELL, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

FRANKLIN R. CARPENTER, Ph. D., Rapid City, South Dakota; Professor of Geology in Dakota School of Mines. May, 1889.

ROBERT CHALMERS, Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

* T. C. CHAMBERLIN, LL. D., Madison, Wis.; President University of Wisconsin.

HENRY M. CHANCE, M. D., Philadelphia, Pa.; Geologist and Mining Engineer. August, 1890.

*† J. H. CHAPIN, Ph. D., Meriden, Conn. (Died March 14, 1892.)

CLARENCE RAYMOND CLAGHORN, B. S., M. E., 204 Walnut Place, Philadelphia, Pa. August, 1891.

*WILLIAM B. CLARK, Ph. D., Baltimore, Md.; Instructor in Geology in Johns Hopkins University.

*EDWARD W. CLAYPOLE, D. Sc., Akron, O.; Professor of Geology in Buchtel College.

AARON H. COLE, A. M., Englewood, Ill. December, 1889.

*JOHN COLLETT, A. M., Ph. D., Indianapolis, Ind.; lately State Geologist.

*THEODORE B. COMSTOCK, Tucson, Ariz.; Directer Arizona School of Mines.

†GEORGE H. COOK, Ph. D., LL. D. (Died September 22, 1889.)

*EDWARD D. COPE, Ph. D., 2102 Pine St., Philadelphia; Professor of Geology in the University of Pennsylvania.

*FRANCIS W. CRAGIN, B. S., Topeka, Kansas; Professor of Geology and Natural History in Washburne College.

*ALBERT R. CRANDALL, A. M., Lexington, Kentucky; Professor of Geology in Agricultural and Mechanical College of Kentucky.

*WILLIAM O. CROSBY, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

CHARLES WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*MALCOLM H. CRUMP, Bowling Green, Kentucky; Professor of Natural Science in Ogden College.

GARRY E. CULVER, A. M., Beloit, Wis.

*HENRY P. CUSHING, M. S., 786 Prospect St., Cleveland, Ohio.

T. NELSON DALE, Newport, R. I.; Assistant Geologist, U. S. Geological Survey. December, 1890.

*JAMES D. DANA, LL. D., New Haven, Conn.; Professor of Geology in Yale University.

*NELSON H. DARTON, United States Geological Survey, Washington, D. C.

*WILLIAM M. DAVIS, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

GEORGE M. DAWSON, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Can.; Assistant Director of Geological and Natural History Survey of Canada. May, 1889.

Sir J. WILLIAM DAWSON, LL. D., McGill College, Montreal, Canada; Principal of McGill University. May, 1889.

DAVID T. DAY, A. B., Ph. D. U. S. Geological Survey, Washington, D. C. Aug., 1891.

FREDERICK P. DEWEY, Ph. B., 621 F St. N. W., Washington, D. C. May, 1889.

ORVILLE A. DERBY, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

*JOSEPH S. DILLER, B. S., United States Geological Survey, Washington, D. C.

EDWARD V. D'INVILLIERS, E. M., 711 Walnut St., Philadelphia, Pa. December, 1888.

*EDWIN T. DUMBLE, Austin, Texas; State Geologist.

Maj. CLARENCE E. DUTTON, Ordnance Department, U. S. A., San Antonio, Texas. August, 1891.

*WILLIAM B. DWIGHT, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

*GEORGE H. ELDRIDGE, A. B., United States Geological Survey, Washington, D. C.

ROBERT W. ELLS, LL. D., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. December, 1888.

* Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor in Amherst College.
* Samuel F. Emmons, A. M., E. M., U. S. Geological Survey, Washington. D. C.
John Eyerman, Easton, Pa. August, 1891.
* Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology and Natural History in University of Rochester.
J. C. Fales, Danville, Kentucky; Professor in Centre College, December, 1888.
Eugene Rudolph Faribault, C. E., Geological Survey Office, Ottawa, Canada. August, 1891.
P. J. Farnsworth, M. D., Clinton, Iowa; Professor in the State University of Iowa. May, 1889.
Moritz Fischer, 721 Cambridge St., Cambridge, Mass. May, 1889.
* Albert E. Foote, M. D., 4116 Elm Ave., Philadelphia. Pa.
William M. Fontaine, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.
* P. Max Foshay, M. S., M. D., 3 Park Ave., Rochester, N. Y.
* Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.
* Homer T. Fuller, Ph. D., Worcester, Mass.; Professor of Geology in Worcester Polytechnic Institute.
Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.
* Grove K. Gilbert, A. M., United States Geological Survey, Washington, D. C.
Adams C. Gill, A. B., Northampton, Mass. December, 1888.
N. J. Giroux, C. E., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.
Uly. S. Grant, B. S., Johns Hopkins University, Baltimore, Md.
* George B. Grinnell, Ph. D., 318 Broadway, New York city.
* William F. E. Gurley, Danville, Illinois.
Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.
* Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.
* James Hall, LL. D., State Hall, Albany, N. Y.; State Geologist and Director of the State Museum.
Henry G. Hanks, 1124 Greenwich St., San Francisco, Cal.; lately State Mineralogist. December, 1888.
John B. Hastings, M. E., Boisé City, Idaho. May, 1889.
* Erasmus Haworth, Ph. D., Oskaloosa, Iowa; Professor of Natural Sciences in Penn College.
* Robert Hay, Box 562, Junction City, Kansas; Geologist, U. S. Department of Agriculture.
C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.
* Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.
Clarence L. Herrick, M. S., 324 Hamilton Ave., North Side, Cincinnati, Ohio; Professor of Geology and Biology in the University of Cincinnati. May, 1889.
* Lewis E. Hicks, Lincoln, Nebraska.
* Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.
Frank A. Hill, 208 S. Centre St., Pottsville, Pa.; Geologist in Charge of Anthracite District, Second Geological Survey of Pennsylvania. May, 1889.

* Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.
* Charles H. Hitchcock, Ph. D., Hanover, N. H.; Professor of Geology in Dartmouth College.
William Herbert Hobbs, B. Sc., Ph. D., Madison, Wis.; Assistant Professor of Mineralogy in the University of Wisconsin. August, 1891.
* Levi Holbrook, A. M., P. O. Box 536, New York city.
* Joseph A. Holmes, Raleigh, North Carolina; State Geologist and Professor of Geology in University of North Carolina.
Mary E. Holmes, Ph. D., 201 S. First St., Rockford, Illinois. May, 1889.
† David Honeyman, D. C. L. (Died October 17, 1889.)
* Jedediah Hotchkiss, 346 E. Beverly St., Staunton, Virginia.
* Edmund O. Hovey, Ph. D., Waterbury, Conn.
* Horace C. Hovey, D. D., Middletown, Conn.
* Edwin E. Howell, A. M., 537 15th St. N. W., Washington, D. C.
† Thomas Sterry Hunt, D. Sc., LL. D., Park Avenue Hotel, New York city. December, 1889. (Died February, 1892.)
* Alpheus Hyatt, B. S., Bost. Soc. of Nat. Hist., Boston, Mass.; Curator of Boston Society of Natural History.
Joseph P. Iddings, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.
A. Wendell Jackson, Ph. B., Berkeley, Cal.; Professor of Mineralogy, Petrography and Economic Geology in University of California. December, 1888.
Thomas M. Jackson, C. E., Morgantown, W. Va.; Professor of Civil and Mining Engineering in West Virginia University. May, 1889.
* Joseph F. James, M. S., Department of Agriculture, Washington, D. C.
Walter Proctor Jenney, E. M., Ph. D., United States Geological Survey, Washington, D. C. August, 1891.
* Lawrence C. Johnson, United States Geological Survey, Meridian, Miss.
* Willard D. Johnson, United States Geological Survey, Berkeley, Cal.
Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.
Edmund Jüssen, Ph. D., Temple, Carroll Co., Ga. December, 1890.
Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.
* James F. Kemp, A. B., E. M., Columbia College, New York city; Adjunct Professor of Geology.
Charles R. Keyes, A. M., Assistant State Geologist, Des Moines, Ia. August, 1890.
James P. Kimball, Ph. D., Washington, D. C. August, 1891.
Clarence King, 18 Wall St., New York city; lately Director of the U. S. Geological Survey. May, 1889.
Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. May, 1889.
* George F. Kunz, 402 Garden St., Hoboken, N. J.
R. D. Lacoe, Pittston, Pa. December, 1889.
George Edgar Ladd, A. B., A. M., Jefferson City, Mo.; Assistant Geologist, Missouri Geological Survey. August, 1891.
J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.
Lawrence M. Lambe, Ottawa, Canada; Artist and Assistant in Paleontology and Geological Survey of Canada. August, 1890.
Alfred C. Lane, Ph. D., Houghton, Michigan; Assistant on Geological Survey of Michigan. December, 1889.

Daniel W. Langdon, Jr., A. B., University Club, Cincinnati, Ohio; Geologist of Chesapeake and Ohio Railroad Company. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

*Joseph Le Conte, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

*J. Peter Lesley, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

Frank Leverett, B. S., 4103 Grand Boulevard, Chicago, Ill. August, 1890.

Josua Lindahl, Ph. D., Springfield, Ills.; State Geologist. August, 1890.

Waldemar Lindgren, U. S. Geological Survey, Washington, D. C. August, 1890.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Thomas H. McBride, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Henry McCalley, A. M., C. E., University, Tuscaloosa County, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., Pittsburg, Pa. August, 1891.

*W J McGee, United States Geological Survey, Washington, D. C.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Canada. August, 1890.

Oliver Marcy, LL. D., Evanston, Cook Co., Illinois; Professor of Natural History in Northwestern University. May, 1889.

Othniel C. Marsh, Ph. D., LL. D., New Haven, Conn.; Professor of Paleontology in Yale College. May, 1889.

P. H. Mell, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

*Frederick J. H. Merrill, Ph. D., State Museum, Albany, N. Y.; Assistant State Geologist and Assistant Director of State Museum.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

James E. Mills, B. S., Quincy, Plumas Co., Cal. December, 1888.

*Albro D. Morrill, A. M., M. S., Clinton, N. Y.; Professor of Geology in Hamilton College.

Thomas F. Moses, M. D., Urbana, Ohio; President of Urbana University. May, 1889.

*Frank L. Nason, A. B., 5 Union St., New Brunswick, N. J.; Assistant on Geological Survey of New Jersey.

*Henry B. Nason, Ph. D., M. D., LL. D., Troy, N. Y.; Professor of Chemistry and Natural Science in Rensselaer Polytechnic Institute.

*Peter Neff, A. M., 361 Russell Ave., Cleveland, Ohio.

*John S. Newberry, M. D., LL. D., Columbia College, New York city; Professor of Geology and Paleontology in Columbia College.

Frederick H. Newell, B. S., U. S. Geological Survey, Washington, D. C. May, 1889.

William H. Niles, Ph. B., M. A., Cambridge, Mass. August, 1891.

*Edward Orton, Ph. D., LL. D., Columbus, Ohio; State Geologist and Professor of Geology in the State University.

*Amos O. Osborn, Waterville, Oneida Co., N. Y.

*† Richard Owen, LL. D. (Died March 24, 1890.)

* Horace B. Patton, Ph. D., New Brunswick, N. J.; Assistant Professor of Geology and Mineralogy in Rutgers College.

Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

Joseph H. Perry, 176 Highland St., Worcester, Mass. December, 1888.

* William H. Pettee, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology, and Mining Engineering in Michigan University.

* Franklin Platt, 1319 Walnut St., Philadelphia, Pa.

* Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

William B. Potter, A. M., E. M., St. Louis, Mo.; Professor of Mining and Metallurgy in Washington University. August, 1890.

* John W. Powell, Director of U. S. Geological Survey, Washington, D. C.

* John R. Procter, Frankfort, Ky.; State Geologist.

* Charles S. Prosser, M. S., U. S. National Museum, Washington, D. C.

* Raphael Pumpelly, U. S. Geological Survey, Newport, R. I.

William North Rice, A. M., Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

* Eugene N. S. Ringueberg, M. D., Lockport, N. Y.

Charles W. Rolfe, M. S., Urbana, Champaign Co., Illinois; Professor of Geology in University of Illinois. May, 1889.

* Israel C. Russell, M. S., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

* James M. Safford, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.

Orestes H. St. John, Topeka, Kansas. May, 1889.

* Rollin D. Salisbury, A. M., Madison, Wis.; Professor of General and Geographic Geology in University of Wisconsin.

* Charles Schaeffer, M. D., 1309 Arch St., Philadelphia, Pa.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

Alfred R. C. Selwyn, C. M. G., LL. D., Ottawa, Canada; Director of Geological and Natural History Survey of Canada. December, 1889.

* Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

Will H. Sherzer, M. S., Ann Arbor, Mich.; Instructor in Geology and Paleontology, University of Michigan. December, 1890.

* Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

* Eugene A. Smith, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

* John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

* J. W. Spencer, A. M., Ph. D., Atlanta, Georgia; State Geologist.

Timothy William Stanton, B. S., U. S. Geological Survey, Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. August, 1891.

* John J. Stevenson, Ph. D., University of the City of New York; Professor of Geology in the University of the City of New York.

George C. Swallow, M. D., LL. D., Helena, Montana; State Geologist; lately State Geologist of Missouri, and also of Kansas. December, 1889.

Ralph S. Tarr, Cornell University, Ithaca, N. Y. August, 1890.

Maurice Thompson, Crawfordsville, Ind.; lately State Geologist. May, 1889.

* Asa Scott Tiffany, 901 West Fifth St., Davenport, Iowa.

*James E. Todd, A. M., Tabor, Iowa; Professor of Natural Sciences, Tabor College.

*Henry W. Turner, U. S. Geological Survey, Washington, D. C.

Joseph B. Tyrrell, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

*Edward O. Ulrich, A. M., Newport, Ky.

*Warren Upham, A. B., 36 Newbury St., Somerville, Mass.; Assistant on the U. S. Geological Survey.

*Charles R. Van Hise, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist U. S. Geological Survey.

*Anthony W. Vogdes, Alcatraz Island, San Francisco, Cal.; Captain Fifth Artillery, U. S. Army.

Charles Wachsmuth, M. D., Burlington, Iowa. May, 1889.

*Marshman E. Wadsworth, Ph. D., Houghton, Mich.; State Geologist; Director of Michigan Mining School.

*Charles D. Walcott, U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

Lester F. Ward, A. M., U. S. Geological Survey, Washington, D. C.; Paleontologist U. S. Geological Survey. May, 1889.

Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

David White, U. S. National Museum, Washington, D. C.; Assistant Paleontologist U. S. Geological Survey, Washington, D. C. May, 1889.

*Israel C. White, Ph. D., Morgantown, W. Va.; Professor of Geology in West Virginia University.

*Charles A. White, M. D., U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

*Robert P. Whitfield, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

*Edward H. Williams, Jr., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

*George H. Williams, Ph. D., Johns Hopkins University, Baltimore, Md.; Professor of Inorganic Geology in Johns Hopkins University.

*Henry S. Williams, Ph. D., New Haven, Ct.; Professor of Geology and Paleontology in Yale University.

*† J. Francis Williams, Ph. D., Salem, N. Y. (Died November 9, 1891.)

*Samuel G. Williams, Ph. D., Ithaca, N. Y.; Professor in Cornell University.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

*† Alexander Winchell, LL. D. (Died February 19, 1891.)

*Horace Vaughn Winchell, 10 State St., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota.

*Newton H. Winchell, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

*Arthur Winslow, B. S., Jefferson City, Mo.; State Geologist.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Instructor in Petrography, Harvard University. December, 1889.

Robert Simpson Woodward, C. E., U. S. Coast and Geodetic Survey, Washington, D. C. May, 1889.

*G. Frederick Wright, D. D., Oberlin, Ohio: Professor in Oberlin Theological Seminary.

Lorenzo G. Yates, M. D., Santa Barbara, Cal. December, 1889.

INDEX TO VOLUME 3.